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CONTENTS

THE COVER: Thirty-foot parabolic antenna (at left) is vital link in the communication system joining this DEW Line station in the Arctic to others. (See story on page 450.)

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Adhesion of Solids: Principles and Applications

O. L. ANDERSON *Mechanics Research*

The theory of adhesion between solids has now been well substantiated, and on the basis of this theory, research and development have resulted in a number of significant experiments and practical applications. At Bell Laboratories, a recent major outcome of this work has been the use of thermocompression bonding to attach wire leads to brittle non-metals like silicon and germanium. This technique promises great simplifications in fabrication and improvements in electrical characteristics of semiconductor devices.

If we squeeze two solids in contact, say one piece of metal against another, they may stick or sometimes even cold weld together. And if we slide one of the solids across the other, friction and wear frequently result. These mechanical effects are of course important to almost all industry; underlying them is a phenomenon known as adhesion. In telephone equipment, for example, adhesion has implications that extend all the way from the wear on a bearing enclosing a rotating shaft to the sticking of two tiny pieces of contact metal in a relay. Adhesion is frequently a nuisance to be overcome so far as possible, as in many problems involving friction, wear, and sticking. But it is sometimes a desirable phenomenon, as in the solderless wrapped connection* where adhesion between the wrapped conductor and the terminal causes the connection to become more reliable with time.

Friction and the control of friction have of course been studied for many years as problems in engineering. With a knowledge of the more commonly used metals and lubricants, it is usually possible to design moving parts and machinery with reasonable accuracy. There are many special situations, however, that elude analysis without fundamental, theoretical techniques for observing and measuring adhesion. Later in this article, several results of recent work on adhesion will be described, but to understand their significance, it is well to review some of the basic facts of adhesion that have been discovered by research in this field.

Much of the fundamental knowledge has come from Professor F. B. Bowden and his colleagues in the Laboratory on the Physics and Chemistry of Surfaces at Cambridge, England. Research in this field has also been done at Bell Laboratories, particularly on the mixing of metals during adhesion and on the adhesion properties of a wide variety of materials. As a result of this work, friction is now well understood and is described by what is known as the "Adhesion Theory of Friction," referred to in the United States as the "stick-slip" theory.

This theory has been developed, not in terms of the broad or large-scale features of solids, but in terms of their microscopic structures — the physics, chemistry, and metallurgy of very small areas of solid materials in contact. It deals with such entities as the tiny projections from an apparently smooth surface of a solid material, and the way these projections or asperities deform and change under localized pressures.

Consider two carefully cut and highly polished one-inch cubes. Placed together, they would seem to have a contact area of one square inch, but the

* B.S.T.J., 33, *pages* 1093-1110, *September*, 1954; RECORD; *February*, 1954, *page* 41.

real area of contact (as calculated from resistance measurements) might be less than 1/100,000 square inch. The reason is that although to the naked eye the surfaces are perfectly flat, under a powerful microscope they might look like relief maps of the Alps. Figure 1(a) is an artist's representation of

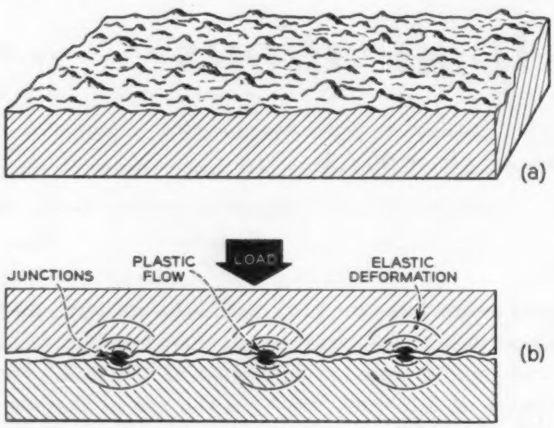


Fig. 1 — (a) Enlarged surface of "smooth" copper — drawing represents magnification of about 4,000 diameters with asperities about 2 microns high; and (b) junctions formed by contact of two surfaces.

the actual appearance of a very smooth copper surface magnified about 4,000 diameters. Therefore, when two such surfaces are placed together, the actual contact area is limited to contacts of the projections or asperities, as in Figure 1(b).

The behavior of such microscopic asperities is quite different from that of larger areas of materials. First, it should be noted that the real pressure in such a microscopic area is much higher than the apparent pressure, defined as the total load pressing the two solids together divided by the *apparent* area of contact. Even under very light loads, in fact, the pressure on a junction between two asperities will be the maximum pressure, P_m, the material will support. An increase in load will result in deformation and plastic flow near the junctions, as shown in Figure 1(b), with the result that the asperities will crush down deeper into the valleys, and the real area of contact will increase. The maximum pressure, P_m, is a measure of the real area of contact: the total load in pounds, divided by P_m in pounds per square inch, yields the real contact area in square inches.

This consideration, however, has neglected a second important phenomenon of adhesion — cold working. Just as iron increases in strength under the blows of a smith's hammer, so the crushing of the asperities cold works them into a tougher condition. That is, P_m often rises under the applied pressure.

The end result of pressing two solid materials together is thus a series of junctions between asperities, and the central problem in adhesion studies is the determination of the manner of formation and behavior of these junctions in varying circumstances. A considerable amount of information is available on this subject, but it might be interesting to point out a few of the more general facts.

The junctions are very much stronger than the parent material, as evidenced by the fact that softer base material is pulled off with the junctions when two solids are separated. Junctions will sometimes pull off the softer material even when the solids are not actually separated. Mere removal of the load pressing them together can cause such breaking, because of elastic stresses that tend to restore their original shapes. Hard solids, or solids with junctions between hard oxides, will break apart readily, and evidence of adhesion is found only by microscopic examinations. Soft metals like well annealed gold will tend to adhere to other solids, hard or soft — they form intimate contact without springing back when the load is removed.

Another important phenomenon in junctions is that they sometimes behave differently under normal and shear loads. For example, with two solids

Fig. 2 — Photomicrograph by F. G. Foster showing black-dyed oxide ripped and abraded from aluminum surface (magnification 100 diameters).

stuck together, it is often easier to twist them apart (shear force) than to pull them apart (normal force). And the reverse is also true – junctions form much more easily when the solids are twisted together than when they are pressed together. This can be visualized if we think of an apparently smooth surface as actually being, microscopically, like a piece of sandpaper, which will abrade much more efficiently if it is rubbed against wood than if it were merely pressed against the wood.

The effect of surface films on adhesion is also very important. Except under extremely high vacuum, most solids form surface films of various sorts; metallic oxides are the most familiar. Thus, in studying the way junctions are created, the hardness of

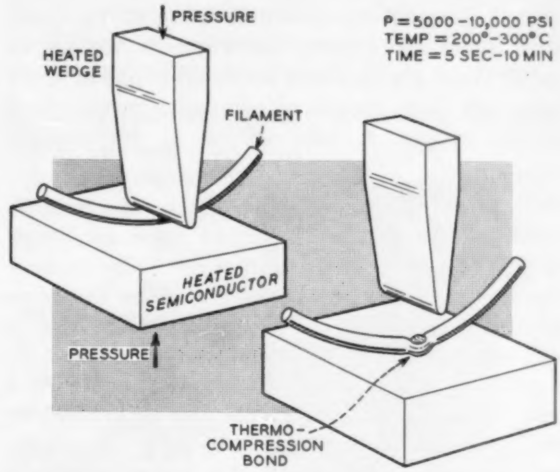


Fig. 3 — The method of making a thermo-compression bond. Resultant bond is strong and reliable.

the film must be taken into account along with the hardness of the material itself. Tin oxide, for example, is 300 times harder than the metal. Contrary to what might be expected, however, such a film is easily pierced by another solid. This phenomenon is sometimes explained with an analogy – it is something like the ease of piercing a film of ice when there is soft mud underneath.

One reason that shear stresses result in strong adhesion is that a twisting or sliding motion between solids accelerates the breaking of surface films. This is illustrated in the photomicrograph shown as Figure 2. Commercial aluminum was anodized in black dye to color the oxide. A steel rod was then butted against the aluminum at 3,000 pounds per square inch and twisted twice. In Figure 2, black is unaffected oxide, white is aluminum from which the oxide has been ripped off, and

Fig. 4 — H. Christensen, the author, and P. Andreatch, Jr., experiment with bonding techniques.

grey is the oxide that has been worn down by grit.

This review of some of the basic facts of adhesion has dealt chiefly with metal-to-metal contacts. Actually, however, it is quite possible to bond metals to nonmetallic materials, as was done in a recently completed joint project of the author and H. Christensen of the Transistor Development Department at the Laboratories. In this project, techniques were developed for the adhesion-bonding of electrical leads to semiconductors like germanium and silicon. These new techniques may solve many of the problems of making contact to small areas without using chemical fluxes and melting in the fabrication of transistors and other semiconductor devices.

The result of this investigation has opened up a new concept in the art of making electrical connections to semiconductors. This method, called thermo-compression bonding, is to be distinguished from soldering and cold welding. It has a number of practical features: (1) the bond can be made quickly in the open air without chemical fluxes, (2) the pressures used are so low that no change in the mechanical or crystal structure of the semiconductor has been detected, and (3) the temperatures used are so low that no evidence of diffusion of the metal into the semiconductor has been detected, nor is there any melting. This connection, made at minimum cost without adversely affecting electrical performance, has the ultimate in strength since the strength of the bonded region exceeds that of the wire used for the connection.

As illustrated in Figure 3, the bond is made simply

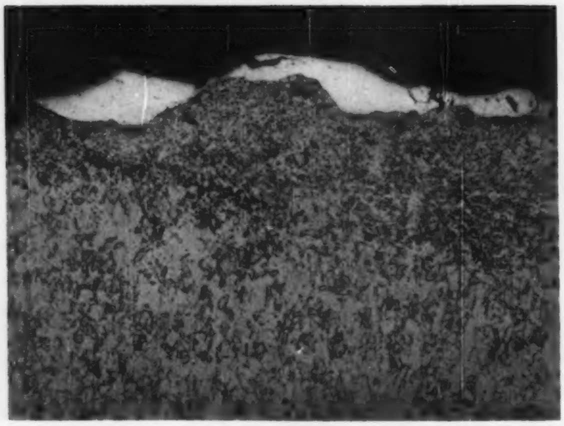


Fig. 5 — Profile of copper surface with large chunks of aluminum remaining after adhering copper and aluminum surfaces have been pulled apart. (Photomicrograph by E. E. Thomas.)

by pressing the metallic wire against a heated semiconductor. Wires of gold, copper, silver, aluminum, platinum, tin, and lead, as well as of a number of alloys of these metals, have all been bonded to both germanium and silicon. Heretofore, applications of this method were limited because gross seizure between most metals was observed to occur only in vacuum. Outside a vacuum, applications were limited because one of the solids had to be an excessively soft material like indium.

Bonding is most successful when the metallic filament is very soft. In such cases, the seizures are not ruptured by restoring elastic forces when the load is removed. A harder noble metal, like platinum, is more difficult to bond than a softer base metal like aluminum, but very pure platinum, made about as soft as aluminum, will adhere easily.

Resistance measurements between gold and germanium show that when adhesion occurs, the resistance across the junction drops by a factor of about ten, indicating that the film separating the two solids is pierced. The magnitude of the final resistance assures almost perfect atomic contact. The stretching of the film under pressure, the raised temperature used in the bonding operation, and the sliding of the gold out from the point of contact, may all be factors in the film penetration. The raised temperature has the effect of keeping the gold junctures from becoming too brittle as they are deformed.

The thermo-compression bond requires some application of heat, but under the right conditions, metal-to-metal adhesion can be established at room temperatures. Recent experimental work in the Mechanics Research area on metal-to-metal adhesion at room temperature has revealed that junctions formerly made only in high vacuum can easily be made in ordinary atmospheres. This work has emphasized the importance of shear stresses in penetrating the oxide films. A simple experiment, first demonstrated by P. Andreatch, Jr., of the Laboratories, using an ordinary shop lathe, illustrates this point. The experiment consists of first placing rods of commercial aluminum and copper, for instance, in the headstock and tailstock of the lathe. If, while the flat ends of the metal rods are pushed together, the tail stock is rotated cyclically through about ten degrees for four cycles, it is found that the two rods are stuck firmly together. The tensile force required to break the bond is often greater than the compression force used to make it. The junctions break more easily, however, in bending or twist. When the two rods are forcibly pulled apart, relatively large chunks of aluminum remain stuck to the copper. A cross section of the common

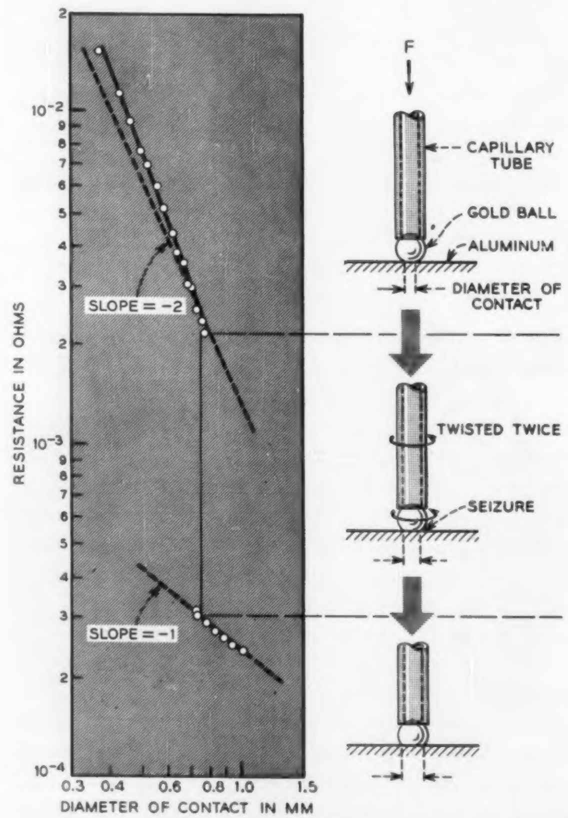


Fig. 6 — Variation of resistance with diameter of contact for gold ball pressed against aluminum. Vertical part of curve indicates piercing of the surface film, at which point resistance drops rapidly.

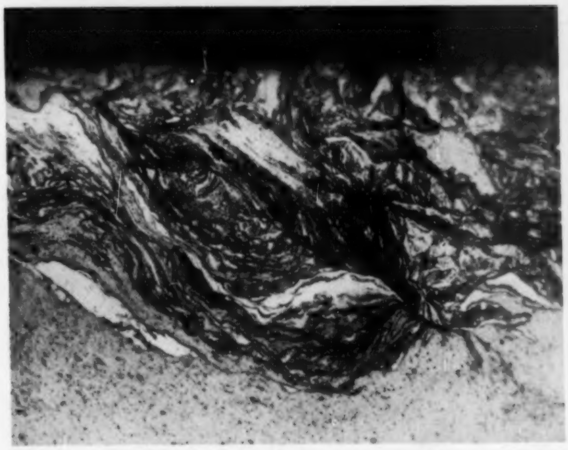


Fig. 7 — Another view of the surface seen in Figure 5; here, aluminum has mixed extensively with the copper. (Photomicrograph by F. G. Foster.)

boundary reveals roughness, penetration and mixing of the metals.

In some regions near the surface, there is only sticking with no mixing, as seen in Figure 5. This shows the large roughness created by the shear, because while the initial roughness was limited to one-tenth mil before shearing, the hills and valleys, as seen in the photograph, are sometimes separated by 5 mils after twisting. In other regions (see Figure 7) there is turbulent mixing of the two metals to depths of 1 mil, with occasional chunks of pure aluminum entirely surrounded by copper. This turbulent mixing is in many ways surprising, because it occurs at axial stresses of less than 5,000 psi and in less than 5 seconds at room temperature.

The effect of shear stresses can be shown by carefully controlling the contact area and measuring the resistance across the junction. To this end, a very soft gold ball was pressed against various plane metallic surfaces. In this instance, the apparent contact area is very close to the real contact area. The ball was pushed with a capillary tube against the metal, and the diameter of contact was measured by shadowgraph techniques. At a selected moment, the capillary was twisted; shear stresses were created at the interface between the ball and plane, and seizure occurred.

The experimental arrangement and the variation of resistance with diameter of the contact surface between gold and aluminum are shown in Figure 6. Before twisting, the resistance varies almost as the inverse square of the diameter, which indicates the presence of an oxide film of high resistivity. When the ball is twisted against the surface, seizure occurs; also, the resistance drops by a large amount, showing that the film is pierced. After seizure, the resistance varies as the first power of the diameter, evidencing pure contact resistance between metals in the absence of surface films. The magnitude of the final resistance indicates that the atomic contact without an oxide film is nearly complete.

The results of the work associated with thermo-compression bonding add a great deal to our understanding of adhesion. We have found that the forces between the solids, which occur at seizure, do not depend seriously upon relative hardness, crystal structure, lattice constants and atomic radii. This is probably due to the versatility of the metallic bond. There is one puzzling feature which requires much more attention, however. We know that the oxide film must be pierced for strong adhesion to occur, but we do not know what happens to the film. The film often behaves as though it suddenly disappeared over the entire region of contact. Obviously, more work on these phenomena is desirable; from it we can expect an even more precise description of the mechanical behavior of metals in contact.

THE AUTHOR

O. L. Anderson, a native of Salt Lake City, received the B.S. degree in Mechanical Engineering from the University of Utah in 1948 and the Ph.D. in Physics, also from the University of Utah, in 1951. In that year he joined Bell Laboratories as a member of the Mechanics Research Group of the Mathematical Research Department. One of Mr. Anderson's chief concerns has been with the mechanical properties of glass, and he has also done research on the relaxation of stress and long-term strength in solderless wrapped connections. More recently, he has engaged in studies of the physical properties of solids under high pressure, and his work on adhesion as related to thermo-compression bonding was an outgrowth of these studies. Mr. Anderson is a member of the American Ceramic Society and is currently chairman of the Society's Glass Division. He is also a member of the Society of Rheology and of the American Physical Society.

The New School for Operating Company Engineers

J. N. SHIVE
Department of Education and Training

In the Operating Engineers Training Program at Bell Laboratories, men from the Operating Companies are introduced to the new devices and systems that may cause revolutionary changes in communications. In this way, the Bell System will have a nucleus of engineers who can use the new technology with maximum speed and efficiency. The engineers spend two years studying and working with the latest solid-state and vacuum devices and the systems in which these devices will be used.

Lester Morris was tired. And he had good reason to be, for he had just completed his regular Friday stint of about five hours' classroom lecture and discussion. He dusted the chalk off his hands, picked up his notes from the lectern, paused to answer one more question, and then edged his way out the door and down the hall toward the canteen for a cup of coffee and further conversation on an informal level with his students.

This is part of a typical school day in the new Operating Engineers Training Program, in which Lester Morris is the instructor-in-charge of a 56-hour course in the fundamentals of transmission circuits and systems. Except for the people who have had actual contact with this program or with the trainees going through it, the O.E.T.P. may appear similar to others of the several educational endeavors in which the Laboratories is currently involved. However, like all these training programs, the O.E.T.P. has its particular objectives and is directed for a particular purpose toward a particular group.

The O.E.T.P. had its genesis in a discussion at a meeting of Operating Company Presidents in 1955. At that time there were many indications of a coming revolution in the techniques of communication. New facilities for data transmission and data handling were in prospect. Transmission between local telephone exchanges by means of coded pulses appeared to have a promising future. Electronic switching systems were in the making, and a transistorized rural carrier system was on field trial. The use of circuits and systems incorporating new electronic elements — varistors, transistors, isolators, gyrators, ferrite cores, ferroelectric memories, and new vacuum devices — was on the verge of an almost explosive expansion. An impending body of new electronic art was thus about to be introduced into the facilities of the Bell System, and the Operating Companies were anxious to be properly prepared to receive, understand and exploit it.

Accordingly, Bell Laboratories was requested to organize a training program in "new-art" techniques to which would be sent selected engineers from the Operating Companies to learn the principles underlying the new devices, new circuits and new systems which would play important roles in future communication. It was envisioned that over a period of years a considerable number of engineers could thus be trained to deal with problems involving new systems when these were ready to be put into use in the telephone network. The A. T. & T. Co. shares with Bell Laboratories some of the responsibilities for organizing the program and helps to provide liaison with the Operating Companies. The Laboratories assumes on its part the arrangement of a suitable curriculum, preparation of texts, furnishing of instructors, and manage-

In the illustration above, Instructor A. H. Budlong leads discussion of new switching techniques.

ment of the "front line" aspects of operating the "new-art" school for the engineers.

The Bell Laboratories' share of the program is under the guidance of a seven-man committee of which Vice-President W. A. MacNair is chairman. This committee in its early meetings formulated the basic policy for the program which, with minor modifications, is now in effect. This policy includes provisions for classroom instruction and recitation, rotational assignments in Laboratories departments where "new-art" developments are in progress, and study both on premises and at home. The day-to-day administration of the school is under the direction of H. E. Sheldon. The responsibility for coordinating the content of the courses and the teaching efforts of the staff lies with the author.

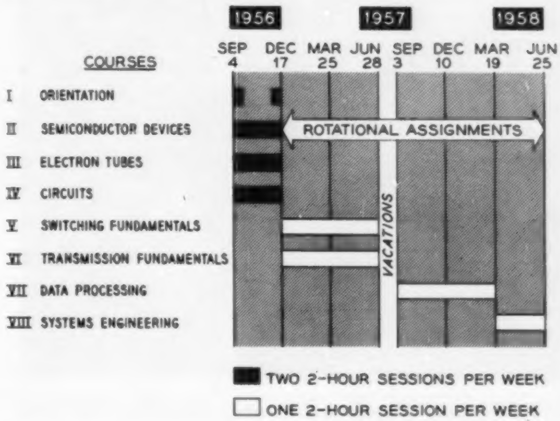
The complete program requires a total of 22 months, which are spent by the trainees in residence at Murray Hill and at such other Laboratories locations where their rotational assignments may take them. The trainees bring their families with them and establish new homes in the northern New Jersey area for the duration of their stay. They remain on the payrolls of their home companies while exercising resident visitor privileges at the Laboratories. Other costs of the program are carried by the A.T.&T. Co.

The selection of trainees to be sent to the O.E.T.P. school is left to the Operating Companies themselves, subject only to a few minimum stipulations imposed to insure that the men selected will be able to profit from their participation in the program. It is strongly recommended that the candidate have a college Bachelor's degree, and that he have a few years' Bell System experience both for background and for demonstration of his potential for future engineering leadership in his company.

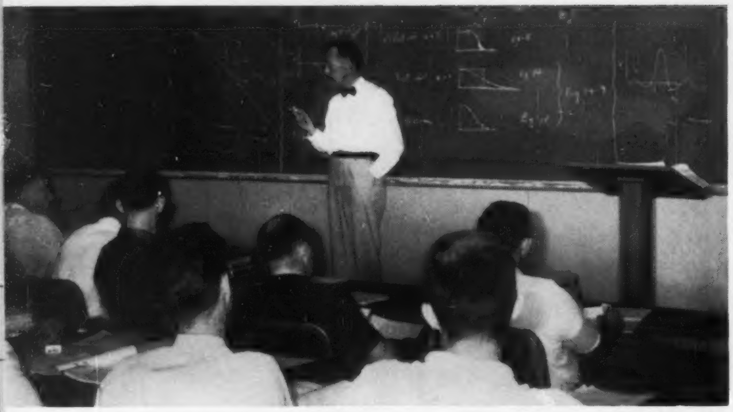
The first class of 48 trainees appeared on the Murray Hill "campus" in September, 1956. They represented all the Operating Companies of the Bell System, including Long Lines and Bell of Canada. Their average age was 31, and they had an average of six years of previous Bell System experience. Since their arrival they have been following the schedule of classes shown in the accompanying illustration. During the first 13-week semester the program consists solely of formal course work and study, with the time spent in class amounting to 12 hours per week. Beginning with the second semester, in December, the class work load is reduced to 4 hours per week, and the trainees begin their first rotational laboratory assignments. A glance at the titles of these courses shows that they cover new devices, new circuits and new systems. The course material is so arranged as to treat during the first semester the devices which are at the heart of the new trend in electronics. The following courses then present the circuit and systems aspects of new communication art based on these devices. For some of these courses, which treat the subject material on a graduate level, texts have been prepared especially for the purposes of the O.E.T.P. school and the objectives of the men in it. Eventually such texts will be prepared for all the courses in the program.

The rotational assignments, which are not made until the trainees have had a three-months' head start on their course work and which, therefore, start with the beginning of the second semester, are allotted on the basis of number of available assignments in the respective departments and on the individual interests of the trainees. The philosophy behind the rotational assignments is that a student can often learn better the practical aspects of a subject by actually participating in a going project than by taking additional class instruction. In most of these assignments the trainee has the opportunity to contribute to the development of the project, and many such contributions have been made. The primary aim, however, is for the trainee to learn by doing rather than to produce a useful output.

The O.E.T.P. headquarters is located in one of the buildings at the Murray Hill location. Here are two classrooms, a student lounge, administrative and secretarial offices, and conference rooms



Schedule of courses and assignments, 1956-1958, of the Operating Engineers Training Program.



In course on transmission theory, Instructor L. H. Morris leads discussion among Operating Company engineers enrolled in the Operating Engineers Training Program.

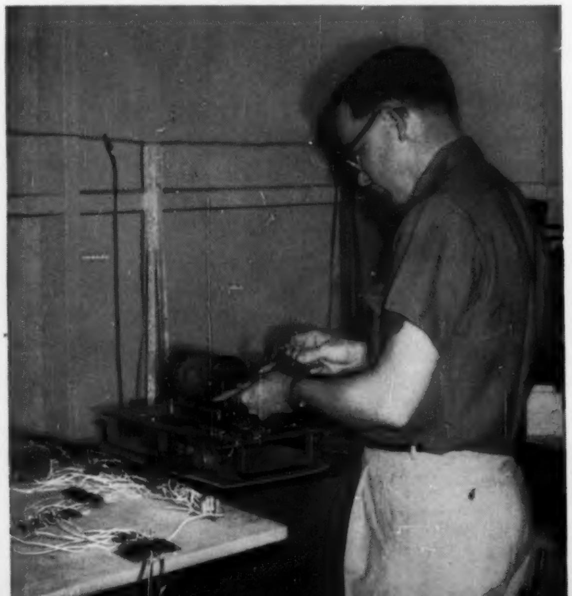
On rotational laboratory assignment, W. Mitchell lines up experimental computer circuit. Students combine studies with actual Laboratories work.

In the O.E.T.P. office, Miss Joyce Varner and Miss Barbara Berg, school secretaries, discuss scheduling problem with R. F. Latter of the Long Lines Department and the author.

In after-class discussion, W. Mitchell (Bell of Canada), J. C. O'Shea (N. J. Bell), and B. B. Oliver (Long Lines) go over transmission mathematics.

Between classes, students in the Operating Engineers Training Program have informal talk with H. E. Sheldon, who serves as the administrator-coordinator for the school.

During rotational assignment at the Laboratories, B. B. Oliver uses punched paper tape in work on an experimental information-processing machine.



for the use of the instructors and students. The classes in the program are conducted informally, and the classrooms are furnished with tables and comfortable chairs to foster the conference-room atmosphere, in preference to the rigid professor-and-student atmosphere of the usual college classroom. During the portions of class days when classes are not in session, the classroom desks are used for study, although the trainees have complete freedom of the campus during non-class hours to study in the Library or student lounge, or to gather by twos and threes in the offices to discuss course material and allied topics informally with the instructors of the courses.

The trainees, as a group, are unusual in many respects. They exhibit a career-minded earnestness which we like to think of as typical of Bell System engineers. They are mature, human and spontaneous. They have elicited favorable comment from their instructors, their rotational supervisors and those of Laboratories management with whom they have come into contact. We find it easy to believe of the group as a whole what was told to us by the Chief Engineer of one of the companies – that the men he was sending to the school were the best he had to send.

Since the proof of any pudding lies in the eating, the question of the extent to which the O.E.T.P. will justify, in long-term benefits to the Bell System, the effort now being invested in it must wait several years for an answer. It is the belief, however, of those who conceived the program, of those who are presently connected with it, and of the trainees within it, that its future value to the System will return many-fold the investment now being committed for its operation.

THE AUTHOR

J. N. Shive, a native of Baltimore, received his B.S. degree from Rutgers University in 1934 and a Ph.D. degree from Johns Hopkins University in 1939. That same year, he joined the Research Department where his first work was on thermistors and selenium rectifiers. During World War II, he was engaged in applying these components to military systems. Following the war, he continued the study of selenium rectifiers and later engaged in various aspects of transistor development. In 1956 he transferred to the Department of Education and Training to assume his present duties in the Operating Engineers Training Program.

Laboratories-N. Y. U. Program Begins with 250 Students

About 250 employees of the Laboratories have enrolled at the Murray Hill branch of the New York University Graduate Center established at the Laboratories.

At a convocation exercise at Murray Hill on September 16, Dr. J. E. Ivey, Executive Vice President of the University, called the establishment of the Graduate Center at the Laboratories a "significant experiment in co-operation between an educational institution and industry."

H. J. Masson, Assistant Dean of the N. Y. U. Graduate Division, urged the Laboratories employees to consider themselves as part of the regular graduate school, free to enter the activities of the University and with full access to its facilities.

The program, offered under the Graduate Division of the N. Y. U. College of Engineering, offers courses which may lead in two years to Masters' degrees in electrical or mechanical engineering and in engineering mechanics.

Classes will be conducted in New York City until the completion of the new building now under construction at Murray Hill. In addition to offices, the new structure will house the Graduate Center.

Laboratories officials taking part in the convocation were E. I. Green, Vice President; F. D. Leamer, Personnel Director; S. B. Ingram, Director of Education and Training; and H. Z. Hardaway and F. R. Michael of the Laboratories' Communication Development Training program.

New York University representatives, in addition to Dr. Ivey and Dean Masson, included N. N. Barrish, Acting Dean of the College of Engineering; R. F. Harvey, Director of the Budget; and S. S. Shamis, Resident Director of the N. Y. U. branch at Murray Hill.

Thirty-Foot Antenna for the DEW Line

R. J. SKRABAL *Outside Plant Development*

Detection of hostile aircraft is the primary purpose of the Distant Early Warning Line that spans the northern reaches of Alaska and Canada. Once aircraft are detected, the information must then be transmitted rapidly and accurately to the appropriate defense command centers. Many links of the communication system designed by Bell Telephone Laboratories' engineers for the DEW Line use "over-the-horizon" methods of radio transmission. Among the projects connected with this work was a thirty-foot parabolic reflector antenna designed for high accuracy and resistance to weather.

Among the many projects undertaken by the Bell System for the United States Government, probably none is better known to the general public than the Distant Early Warning (DEW) Line, for which the Western Electric Company was prime contractor. As part of the project, one of the responsibilities of Bell Telephone Laboratories was the design of the DEW Line Communication network, used to flash warnings from the Arctic to the various defense commands. Because of terrain and weather conditions, the communication system linking the stations in the radar network uses "over-the-horizon," tropospheric-scatter radio transmission. A major component of this communication system is a thirty-foot parabolic reflector antenna, also being used on some links of the "White Alice" Communication System in Alaska.

The Outside Plant engineers of the Laboratories had responsibility for establishing basic structural and mechanical requirements and supervision of the design of this antenna; the actual design and fabrication of the antenna was done by the Blaw-Knox Company of Pittsburgh, Pennsylvania. The delivery schedule – timed to permit erection of the antennas in relatively mild weather – made little allowance for delays. Laboratories representatives were therefore present at the Blaw-Knox plant almost continuously from the beginning of the design stage to the conclusion of the prototype tests – a period of about six months – to coordinate refinement of the design and necessary modifications. Experience gained from previous work on the sixty-foot antenna for "White Alice"* was very useful in solving some of the problems which arose.

To meet transmission requirements, the reflecting surface of the antenna is a paraboloid of revolution with a focal length of nine feet. The rim of the reflector is a circle 30 feet in diameter. The reflector framework consists of twenty equally-spaced ribs, the front flanges of which are formed to the desired parabolic shape. These ribs are supported by a central hub and a circular beam 22 feet in diameter. Diagonal and horizontal bracing maintains the ribs in their proper relative positions. To form the reflecting surface, twenty sectors of 12-gauge steel plate are bolted to the ribs and to connecting an-

* RECORD, *January*, 1956, *page* 37.

gles. The allowable tolerances are such that any point on the reflecting surface must be not more than $\frac{3}{4}$ inch, about $\frac{1}{16}$ wavelength, from the true paraboloid as measured from the focal point.

All structural members of the antenna are of galvanized steel. Bolted connections made in the field are secured with locknuts to resist loosening from vibration or impact. An alloy having good impact properties at low temperatures was selected for the bolt material.

Although the antenna reflector weighs eight tons, it must be mounted on a tower so that the signals will clear foreground obstructions that might interfere with the transmitted beam. Five available tower heights permit locating the center of the reflector from 25 to 75 feet above the tower footings.

The maximum allowable deflection of this structure is 0.5 degree when covered with three inches of ice and subjected to 125 mile-per-hour winds. The actual deflection will be much lower. The antenna was designed to survive a 150 mile-per-hour wind when covered with glaze ice three inches thick, or an 80 mile-per-hour wind when covered with less dense rime ice sixteen inches thick. These strength requirements resulted in an extremely rigid structure. To insure the structure's meeting the design requirements, Laboratories engineers thoroughly checked complete stress and deflection calculations prepared by the contractor.

Fig. 1 — Adjustment of azimuth angle at one of the front legs. The horizontal jackscrew is used to move the base shoe in the horizontal slot.

Fig. 2 — Use of special wrench to move the elevation adjusting nuts at one of rear legs.

The antenna has a gain of about 35 db at frequencies between 755 and 985 mc. The cantilever-mounted aluminum feed may be mounted for either horizontal or vertical polarization of the transmitted signal. It can be retracted through the center of the reflector for maintenance, a novel feature in an antenna of this size. It consists of a length of tapered waveguide and a horn. The primary radiator, or feed horn, consists of two transverse apertures facing the paraboloid with appropriately shaped reflectors within the horn. Windows of polyester-impregnated glass fiber cover the apertures. The mechanical design of the horn flanges produces certain desirable electrical characteristics, and also provides a means for securing the windows. The horn connects through the tapered waveguide section to another waveguide that is about 5 by 10 inches in cross section. Either waveguide or $3\frac{1}{8}$-inch coaxial cable may be used for the connecting transmission line. If coaxial cable is used, an adaptor at the rear face of the reflector provides the transition to the feed waveguide. The feed and the connecting transmission line are both maintained under pressure with dry air to prevent the accumulation of moisture within the system.

Methods of de-icing the antenna were chosen to

Fig. 3 — Reflector being assembled on the ground at a snow-covered DEW Line site in the Arctic.

give the most practical combination of initial cost, reliability, economical use of power, and ease of maintenance. Wires imbedded in the windows electrically heat the apertures in the feed horn to prevent accumulations of ice that would impair transmission. Blanket-type electric heaters are provided on all antennas to de-ice the portion of the waveguide near the horn. Additional de-icing equipment for the reflector and the waveguide portion of the feed horn may be installed on antennas in areas where excessive icing is expected. On a fully de-iced antenna, "Galbestos" encloses the supporting structure adjacent to the reflector. This material, a steel sheeting covered with an asphalt-impregnated asbestos felt, has desirable heat-loss characteristics. Ducts, forming a closed system, direct hot air from two 500,000 BTU-per-hour oil-fired space heaters within the enclosure to the rear of the reflecting surface and through passages in part of the waveguide section of the feed.

Because of the loading conditions to which the structure is subjected, the design of the adjustment details presented some interesting problems. For final electrical alignment of the antenna, the support structure of the reflector can be adjusted up to 3 degrees in either direction from the neutral position in both azimuth and elevation. The front legs of the support structure are pinned at their lower ends. At the rear legs, elevation adjustment screws, 3¼ inches in diameter, are pinned at their lower ends and pass through the leg base plates where they are secured by double nuts on both sides of the plates. Spherical washers allow for the angular movement of the screw in the base plate as the antenna is adjusted in elevation.

Figures 1 and 2 show how the front and rear legs are pinned to the base shoes. These shoes are constrained to move in slots at the corners of the adjustment platform, and the slots are perpendicular to radii from the azimuth pivot point. Thus, the application of horizontal forces — by means of adjusting screws at the two front posts of the upper structure — moves the reflector in azimuth angle about the pivot point. After adjustment in azimuth, clamps on the adjustment platform brace the movable base shoes against shear loads, so that there is no tendency for the shoe anchor bolts to slide in their slots.

To demonstrate the erection procedure, to insure that parts were fabricated properly before production shipment, to check the accuracy of the reflecting surface, and to test the operation of the various adjustments, a complete 75-foot antenna assembly was erected and tested at Pittsburgh. Detail dimensions were checked by determining whether the components fitted together properly. Both waveguide and coaxial transmission lines were mounted on this structure, together with a platform for the mounting of either a UHF or VHF Ground/Air Navigation Aid antenna at the top of the reflector assembly.

Fig. 4 — R. J. Skrabal, R. E. Elicker and N. K. Jorstad discuss erection of the test antenna with the contractor. The fixture for locating the focal point when checking the accuracy of the reflector is mounted in the position normally occupied by the feed waveguide and feed horn.

Two methods for the erection of the reflector were tested. In one case, the reflector was assembled on the ground and lifted into place by two cranes. In the second method, the reflector was assembled piece-by-piece in position on the tower. Both methods proved feasible and resulted in reflecting-surface accuracy well within the desired tolerances. Although a tolerance of ¾ inch from the true paraboloid was permitted, a maximum deviation of only ⅜ inch was found with the three reflectors assembled in Pittsburgh.

For transmission tests of the antenna and tests of the de-icing equipment, a full-size reflector, together with its supporting structure and de-icing equipment, was mounted on a large turntable to permit 360-degree rotation of the antenna for the measurement of radiation pattern. Mounting the antenna just off the ground made it easier to adjust the feed and to place many thermocouples on the reflecting surface to measure temperatures. This antenna was located on a hilltop and was aligned with a mobile test antenna about a mile and a half away. The site had been surveyed previously for the transmission tests of the sixty-foot "White Alice" antenna. The transmission tests were conducted by the General Bronze Corporation, who developed the feed in cooperation with engineers from the Laboratories' Military Electronics Development Department. These tests showed that the electrical performance of the antenna was substantially in accordance with the specified requirements. Tests of the de-icing equipment were conducted at night to take advantage of lower and more constant ambient temperatures. Modifications of the duct system proved necessary to achieve proper heat distribution and the desired temperature rise at the reflecting surface.

As soon as prototype tests showed that portions of the antenna assembly were satisfactory, approval was given for production of these parts. All components, designed for shipment in available aircraft, were delivered to the sites as rapidly as possible to permit assembly before the Arctic winter curtailed construction operations.

THE AUTHOR

R. J. Skrabal, a native of Woodside, N. Y., received the B.S. degree in Mechanical Engineering from Columbia University in 1949. Prior to joining the Laboratories Outside Plant Development Department in 1953, he spent several years in industry. At the Laboratories, he has worked on the design and application of power tools for mechanizing various installation and outside plant operations. He has also engaged in the development of "over-the-horizon" and other microwave antenna structures. Currently, he is concerned with the design of special air-conditioning and tube cooling systems for military and telephone electronic equipment. Mr. Skrabal recently completed the Communication Development Training Program as a special student. He is a member of the A.S.M.E.

Four Honored by Audio Society

The Audio Engineering Society has presented awards to a member of the Laboratories and to a retired member, and has also awarded honorary memberships to two additional members of the Laboratories. These honors were bestowed at the organization's annual banquet in New York City on October 10.

At the banquet, Carleton R. Sawyer received the Audio Engineering Society Award for service to the Society. This was in recognition of his work as Chairman of the organization's Publications Committee in 1955-56. Edward C. Wente, who retired from the Laboratories in 1954, received the Society's John H. Potts Award for outstanding achievements in audio-engineering. Mr. Wente was cited for his contributions to the recording and reproducing of sound, for his development of the condenser microphone, and for his original work on stereophonic transmission and sound recording on magnetic tape.

The honorary memberships were presented to Warren P. Mason and to Harry Nyquist of the Laboratories. Mr. Mason was honored for his work in electrical and mechanical wave transmission networks and in the development of transducers. Mr. Nyquist's honorary membership was bestowed in recognition of his stability diagram for negative feedback circuits and for his extensive work in the field of communication.

U.S.-Hawaii Telephone Cable System in Service

Plans for Second Transatlantic System Announced

The world's longest and deepest telephone cable system, linking the U. S. Mainland with Hawaii, was opened to public service on October 8. Earlier, the A.T.&T. Co. on September 30 signed contracts with French and German agencies for construction of a second telephone cable system across the Atlantic Ocean.

Cables for the Hawaiian system cross the Pacific from Point Arena, California, to Hanauma Bay near Honolulu – a distance of some 2,400 miles with ocean depths up to three and a half miles. Plans for the second transatlantic system also call for cables spanning about 2,400 miles, between Clarenville, Newfoundland, and Penmarch, France, on the Brittany Peninsula.

Operator Dialing

The opening of the U. S.-Hawaii system, which followed an exchange of greetings among dignitaries at Washington, San Francisco and Honolulu, introduced a new feature to overseas telephony – operator dialing. When a call is to be made, mainland or Island operators can key or dial the number, and in a few seconds the called telephone across the Pacific will ring. The system requires two cables – one for east-west transmission and the other for west-east transmission.

The $37,000,000 deep-sea cable system, built by the A.T.&T. Co.'s Long Lines Dept. and the Hawaiian Telephone Company, was hailed by Frederick R. Kappel, President of A.T.&T., as the fulfillment of present-day needs for communications between the Islands and the Mainland. Mr. Kappel said he believed that in the foreseeable future communications between continents would be as fast, convenient and dependable as they are today within the U. S.

Mr. Kappel added: "Today, as we open this new cable under the Pacific, we are also preparing to build another one under the Atlantic. This will extend directly to the European Continent, and agreements that permit going ahead with the work were signed a week ago yesterday . . . I believe that in the future, we shall have entirely practical and feasible means for transmitting television pictures across oceans. Our job is to provide service that will be the best possible, and that is what we shall always be trying to do."

The Pacific Telephone & Telegraph Co. also participated in the project, constructing a 125-mile radio-relay link that connects the cable circuits with the nationwide telephone network at Oakland, California.

The opening ceremonies were held in the Treaty Room of the Executive Office Building in Washington. Mr. Kappel acted as master of ceremonies. Other participants in Washington were Secretary of Defense Charles E. Wilson; Postmaster General Arthur E. Summerfield; General Nathan F. Twining, Chairman of the Joint Chiefs of Staff; John C. Doerfer, Chairman of the Federal Communications Commission; and Henry T. Killingsworth, Vice President of A.T.&T. in charge of its Long Lines Department.

At the ceremonies, Mr. Wilson read a message from President Eisenhower: "Please give my greetings to all participating in the ceremony marking the completion of the underwater telephone cable system between the mainland of the United States and the Hawaiian Islands. I know this splendid addition to the nation's network of communications will encourage economic and social ties between the mainland and the Islands and strengthen our common defense. It is a pleasure to send congratulations to the two companies which have completed this outstanding achievement with skill, courage and vigorous effort."

Aboard the cable ship Ocean Layer, *P. W. Rounds of the Laboratories measures transmission performance of cable as it is being laid.*

18,000-mile Call

Inaugural conversations included one which extended from Washington to London, back to Ketchikan, Alaska, via New York and Seattle, and on to Honolulu. This call was 18,000 miles in length and used all three deep-sea cables placed by A.T.&T. during the past year – the transatlantic, the Alaskan cable and the new one to Hawaii. After the ceremonies, the Pacific cable system was opened for commercial use.

Years of research and development made construction of the system possible. Much of the work was devoted to the design of the repeaters, needed to boost the strength of signals after they suffer attenuation along the cable. These amplifiers were developed by Bell Laboratories and manufactured by the Western Electric Company. They are built into the cables at 44-mile intervals and are designed to withstand the terrific pressures encountered in the ocean depths. They amplify voice currents over 1,000,000 times and have been designed for a high degree of reliability.

Five Laboratories members took part on-the-scene in the cable laying. Overseeing the Laboratories part of the project was R. D. Ehrbar, and P. W. Rounds and W. A. Klute were aboard the vessels laying the cable. T. F. Gleichmann and D. Robertson worked at the cable land terminals in Point Arena, Calif., and in Hawaii.

Second Transatlantic Cable

In announcing plans for the second transatlantic cable, Mr. Kappel said that the move was prompted by the success of the first transatlantic system. "The introduction of the first underseas telephone cable, which links this continent to Great Britain and via Great Britain with eight countries on the continent, has been an unqualified success," Mr. Kappel said. "In less than a year, traffic to Great Britain has gone up 100 per cent and traffic to the continent 50 per cent." He said that construction of the new system would start immediately and be completed in 1959.

Mr. Kappel also cited these facts about the new cable system: It will cost about $40,000,000. Sixty-four per cent of the cost will be borne by the American Company, the remainder by the French and Germans. Construction of the system will be under direction of the American Company, and both cables are to be laid in the summer of 1959.

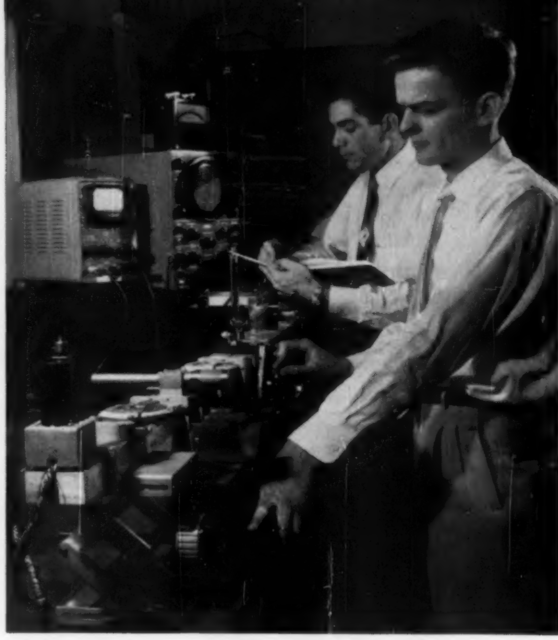
Bell Laboratories will assist the Long Lines Department of the A.T.&T. Co. as required in the detailed design of the new transatlantic system and in the equalization procedure during the laying operations. Laboratories personnel will also assist Western Electric and Long Lines in setting up cable manufacture in France and Germany and in assuring that design requirements are met in these factories as well as others in Great Britain and the United States. This will require the transfer of some Laboratories people to Western Electric for overseas residence throughout the project.

A.T.&T. President Frederick R. Kappel signing contracts on September 30. Seated, Mr. Kappel and W. G. Thompson, President, E.T.&T. Co. Standing, C. W. Phalen, Executive Vice President, A.T.&T.; G. L. Best, Vice President, A.T.&T.; A. B. Goetze, President, W.E. Co.; H. T. Killingsworth, Vice President of Long Lines; H. I. Romnes, Vice President, A.T.&T.; and Dr. M. J. Kelly.

Electron tubes and gas tubes for the repeaters will be fabricated under conditions of extreme care and hospital-like cleanliness at the Murray Hill Laboratories location. As with previous cable systems, Laboratories people will continue in attendance at the Western Electric plant in Hillside, N. J., to provide the close liaison necessary for assurance that the repeaters meet the very high design standards of submarine cable service.

Parties to the contracts for the new system include the French Ministry of Posts, Telegraph and Telephones; the German Federal Ministry for Posts and Telecommunications; Eastern Telephone and Telegraph Company and A.T.&T. The French and German agencies are responsible for telephone services within their respective countries. Eastern Telephone and Telegraph Company, a Canadian subsidiary of A.T.&T., now owns jointly with Canadian Overseas Telecommunication Corporation and the British Post Office a radio-relay system from the United States to Sydney Mines, Nova Scotia, which will be used by the new system. The contract became final with the signing by Mr. Kappel and by William G. Thompson, President of E.T.&T. Signatures of the other parties had been previously obtained.

When a light beam shines on any surface, some light will be reflected. Similarly, some microwave energy from a transmitter is reflected from discontinuities in radio-relay system equipment. These reflected waves can often lead to adverse transmission effects. One way of eliminating them without seriously reducing the strength of the transmitted signal is through the use of ferrite slabs in the form of field displacement isolators. The article on page 460 tells the story of patents associated with this development.



Field Displacement Isolator in Microwave Communications

S. WEISBAUM AND H. BOYET *Solid State Device Development*

In a microwave radio relay system, wave reflections occur from the transmitting antenna and from irregularities in the waveguide system. If these reflected waves are not suppressed, they may have a deleterious effect on the performance of various microwave components and, thereby, of the entire system. A klystron oscillator, for example, may have its frequency changed* when a reflected wave reaches it and, as a result, the transmitted signal will be distorted. The magnitude of this effect increases with the length of the waveguide-run to the antenna (called the "long-line" effect). In the case of a traveling wave tube, unwanted reflections reaching the output of the tube can give rise to echoes out of phase with the main signal. In television transmission, such echos produce so-called "ghosts." It becomes important, therefore, to block out undesired reflections that may reach certain components of a microwave system.

Reflected waves in a microwave system could be suppressed by inserting conventional attenuators in front of the components to be protected. Attenuators of this sort, however, dissipate a certain fraction of energy incident upon them. Although such elements can protect components from reflected signals, they also dissipate the main signal by a large amount. The use of such "pads" has a definite disadvantage even in microwave test circuits because the signal power may be reduced so much that it is difficult to measure accurately.

An element is therefore needed which can dissipate a large fraction of reflected energy and, at the same time, affect the power level in the forward or transmitting direction to a negligible degree – a nonreciprocal device. Such an element has been called an isolator. With a device of this sort, transmitted waves would reach the antenna essentially unattenuated while reverse waves set up by reflections would be largely dissipated in the isolator (Figure 1).† Certain magnetic materials with high resistivities – ferrites – make it possible to construct such nonreciprocal circuit elements. In fact, these materials have been used in the Faraday rotation isolator.

The Faraday rotation isolator is a circular waveguide device which may be used in rectangular waveguide circuits provided the proper rectangular-to-circular waveguide transitions are used. It would be advantageous, however, to have an isolator designed specifically for use in rectangular wave-

* RECORD, *October*, 1955, *page* 385, and *April*, 1955, *page* 131. † RECORD, *November*, 1955, *page* 419.

guides. Furthermore, there are applications in microwave relay systems in which the forward loss (loss in the transmitting direction) must be lower over a given bandwidth than that which has been attained with the Faraday rotation isolator. Conversely, other systems require a higher reverse loss than has been provided by the Faraday isolator over a broad band. An investigation of rectangular waveguide isolators was consequently undertaken.

In this application, a rectangular slab (or slabs) of ferrite is used in a rectangular waveguide and a dc magnetic field is applied to the ferrite perpendicular to the direction of wave propagation. S. E. Miller of Bell Telephone Laboratories was among the first to consider the "field displacement" property produced by this configuration and investigate it as a possible basis for a microwave isolator.

The presence of a ferrite slab and dc magnetic field in the waveguide, as shown in Figure 2, results in a different electric field distribution across the guide for the forward, or incident, direction of propagation as compared with the reverse, or reflection, direction of propagation. Placing a strip of resistive material on the ferrite slab results in more electric energy being dissipated for one direction of propagation than for the other direction. This difference in attenuation in the two directions is responsible for the isolator action of the device.

To see how the field displacement effect comes about, it is desirable to briefly review the physics of ferrites. All electrons have charge, mass and spin. The charge and spin of an electron produce a magnetic field directed along its spin axis. In fact, the magnetic field of the spinning electron may be thought of as being produced by a bar magnet of electron size. In most matter, the magnetic fields of all the spinning electrons cancel out so that the material does not exhibit any net magnetization. In ferrites, however, the spins of the electrons line up in parallel directions, with the result that there are domains of small but finite size, each of which exhibits a net magnetization. The magnetizations in the various domains normally are not parallel to each other, but when an external dc magnetic field is applied to the ferrite, the "electronic bar magnets" in all the domains line up with that field. The sample as a whole thus exhibits a net value of magnetization.

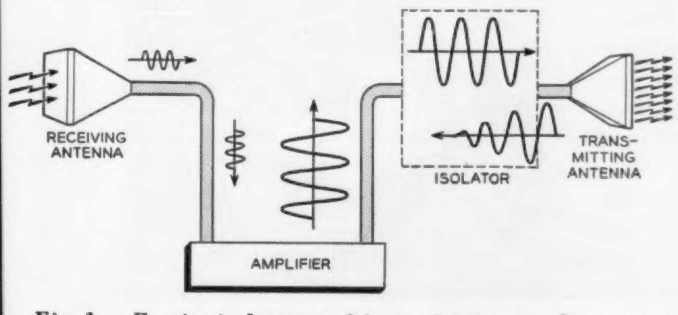


Fig. 1 — Ferrite isolator used in a microwave relay system.

A radio-frequency electromagnetic wave cannot penetrate certain magnetic materials, such as iron, because of their low resistivities (about 10^{-5} ohm-cm). Because of the ferrite's high resistivity (above 10^6 ohm-cm), however, RF waves can pass through them. If the magnetic field in an electromagnetic wave is polarized in a plane at right angles to the external dc magnetic field applied to the ferrite, then, as the wave passes through the ferrite slab, the little bar magnets previously described interact with the magnetic field of the wave and no longer remain parallel to the dc magnetic field. They will precess about the dc field much as a spinning top or gyroscope precesses about the earth's gravitational field. The frequency of this precession is proportional to the strength of the dc magnetic field applied to the ferrite. For typical values of applied magnetic field, these precessional frequencies can be made to lie in the microwave region of the electromagnetic spectrum.

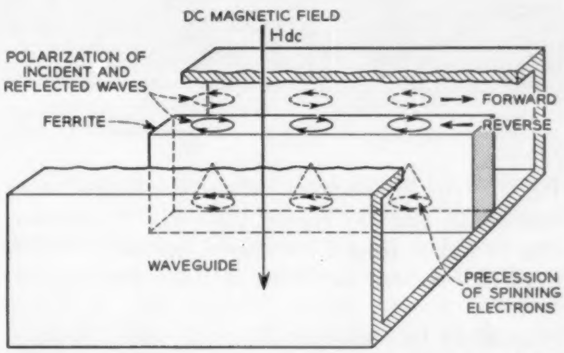


Fig. 2 — Polarizations of incident and reflected RF waves in a rectangular waveguide, and precession of spinning electrons in a ferrite slab.

The precession of the elementary spinning magnets in a ferrite slab located in a rectangular waveguide is shown schematically in Figure 2. This figure also illustrates the polarizations of the RF magnetic field for the forward-traveling wave coming from the generator (dashed ellipses) and for the reflected wave coming back from the antenna or some other discontinuity (solid ellipses). The dc magnetic field is labeled H_{dc}.

The electric field distribution* associated with an RF wave in an empty waveguide is shown in Figure 3(a). If a ferrite slab is inserted in the waveguide, as shown in Figure 2, this electric field distribution is distorted. Since the polarizations of the forward and reverse RF waves are opposite in sense

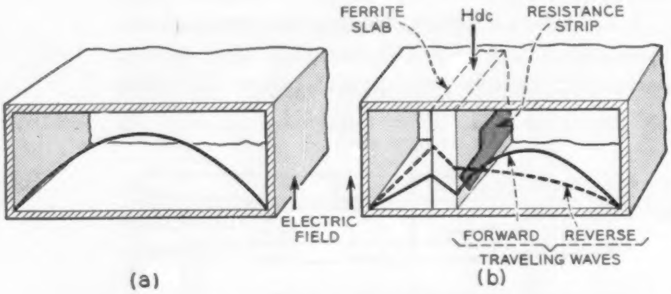


Fig. 3 — (a) RF electric field distribution in empty waveguide, and (b) typical electric field distribution in ferrite loaded waveguide assembly for forward and reverse directions of wave propagation.

(Figure 2) they interact differently with the indicated spin precessions – the polarization of one wave is in the same sense as the precession, and that of the other wave is in the opposite sense. The interaction, resulting from the passage of an RF electromagnetic wave through the ferrite in one direction, increases the amplitude of the electron precession. Similarly, an RF wave in the other direction decreases the amplitude of precession. As a result of these interactions, the radio frequency magnetic flux inside the ferrite is different for the two directions of propagation. In other words, the ferrite presents unequal magnetic permeabilities to the RF waves for the two directions of propagation.

Since the distribution of the RF electric field intensity in a waveguide depends on the permeability of the medium in the guide, the simple curve illustrated in Figure 3 is distorted. The different permeabilities for the two directions of propagation result in different RF electric field configurations in the waveguide for these two directions. It is this difference in the electric field strengths due to the "field displacement" effect that provides the basis for using a ferrite slab as a microwave isolator. Solving Maxwell's electromagnetic equations with the appropriate values of permeability for each direction of propagation yields the theoretical electric field distributions associated with forward and reverse waves. Typical distributions of this sort are illustrated in Figure 3(b).

* Fundamental TE mode.

To make use of this difference in electric field strength in providing a microwave isolator, a strip of resistive material is placed on one face of the ferrite slab. A strip of this sort dissipates the energy in an electric field by an amount proportional to the square of the electric field strength at the strip. As shown in Figure 3(b), the electric field strength associated with the forward traveling wave is low in the area near the resistive strip, and hence this wave travels down the guide essentially unattenuated. Conversely, the field strength is high for the reverse wave in the same area and the strip therefore dissipates considerable energy from that wave. In this way, the electric field configurations, or "field displacement effect," provide the nonreciprocal attenuation necessary for isolation.

To optimize the performance of the isolator over as broad a frequency band as possible, a number of parameters, some of which are illustrated in Figure 5, must be properly adjusted. Some of the parameters which affect the forward and reverse electric field distributions include; ferrite height (h), ferrite thickness (δ), a distance of ferrite from nearest side wall (b), saturation magnetization ($4\pi M_s$), applied dc magnetic field (H_{dc}), placement of resistance material, and resistivity (ρ).

Since the isolator is used to block reflected waves, it is necessary to keep reflections from the isolator itself to a minimum. To do this a ferrite slab is used which is less than the full height of the waveguide (see Figure 5). With such a "partial-height slab" a smaller portion of the incident wave is converted into a reflected wave. (This comes about

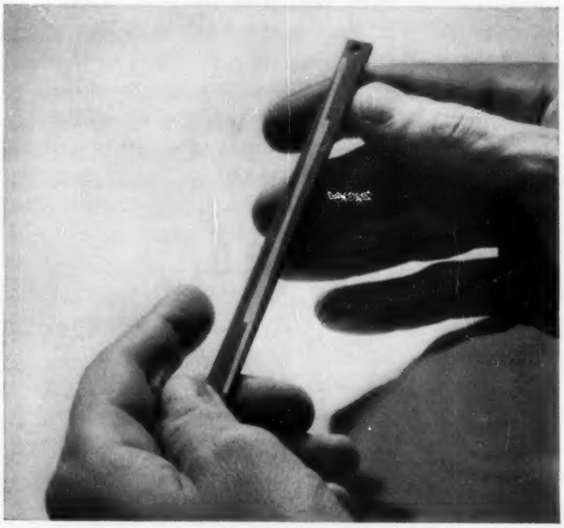


Fig. 4 — Ferrite slab incorporated in the isolator.

from certain mathematical boundary conditions which must be satisfied.) As a consequence, a considerably smaller voltage-standing-wave-ratio (VSWR) is obtained with the partial-height ferrite than would be obtained in the full height case. The smaller the VSWR the smaller the amplitude of the reflected wave. In addition, longitudinal components of the electric field (parallel to the direction of propagation) are generated because of the partial height geometry. These have been found to be nonreciprocal in such a way as to improve isolator performance.

The thickness of the ferrite and its distance from the waveguide sidewall are important in determining the electric field distributions in the islator for the two directions of propagation. The parameters can be adjusted so as to yield a small transverse electric field at the ferrite face for the forward

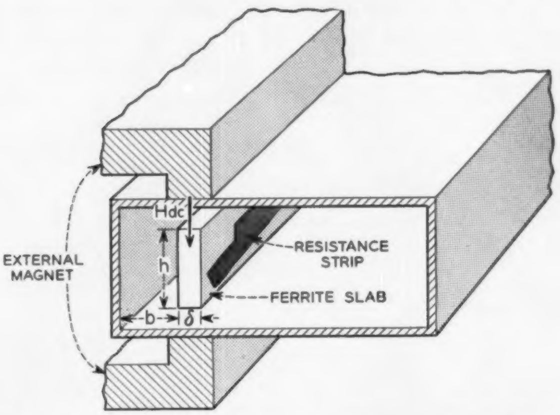


Fig. 5 — Assembly of ferrite, resistance material, magnet and waveguide for ferrite isolator.

direction of propagation resulting in low forward loss, and at the same time to yield a large electric field at the ferrite for the reverse direction of propagation giving high reverse loss.

When the frequency of an RF wave coincides with the natural precession frequency of the electron spins in a ferrite, ferromagnetic resonance occurs. Because of the large absorption of microwave energy at resonance, the forward loss may increase. It is therefore necessary to choose a dc magnetic field and ferrite saturation magnetization (governed by the nature of the ferrite itself) such that the resonance frequency is far from the operating frequency. In addition, the practical consideration of physical size limits the dc magnetic field. These conditions lead to a choice of large saturation magnetization and small dc magnetic field in the actual construction of an isolator.

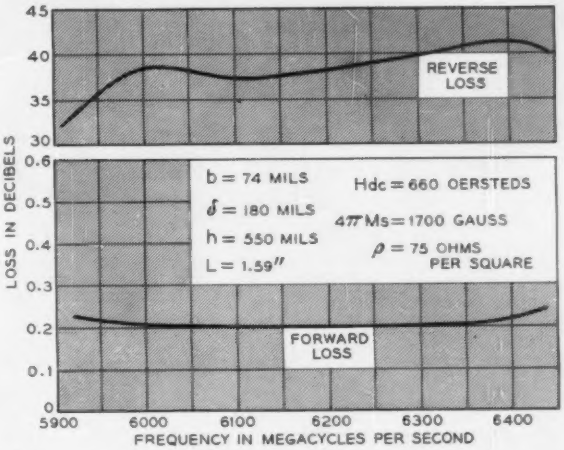


Fig. 6 — Performance of field displacement isolator.

Perhaps the most important parameter determining the performance of the field displacement isolator is the configuration of the resistance material placed on the ferrite face. A novel disposition of this material makes use of the nonreciprocal nature of the longitudinal components of electric field set up by the partial-height ferrite. Resistance material is placed in a region where both the fundamental transverse component and the longitudinal component of the electric field are small in the forward direction but large in the backward direction of propagation. This configuration, shown in Figure 4, consists of a baked resistance coating of graphite and resin covered by a baked clear coating. The length of the resistance material is critical in determining the forward and reverse attenuation. Experiments indicate, however, that the attenuation is not simply a linear function of the length of the strip.

The best results obtained to date with field displacement isolators of the type described are summarized in Table 1 for four frequency bands. A

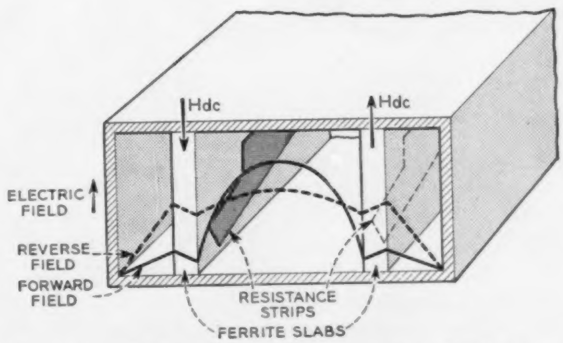


Fig. 7 — Typical electric field distributions in isolator with second slab placed in waveguide.

TABLE I — PERFORMANCE OF SINGLE-SLAB FIELD DISPLACEMENT ISOLATORS IN VARIOUS FREQUENCY BANDS

Frequency Range (Mc/sec)	*Maximum Forward Loss (db)*	*Minimum Reverse Loss (db)*	*Maximum VSWR*
3700-4200	0.3	20	1.07
5925-6425	0.2	30	1.06
10,700-11,700	0.25	28	1.07
23,500-24,470	0.6	34	Not Measured

more detailed description of isolator performance is given in the forward and reverse loss versus frequency curves in Figure 6. These curves and the operating parameters listed apply to isolator use in the indicated frequency band.

In one microwave system, the longline effect and the relatively high operating frequency impose stringent requirements on the reverse loss — it should be greater than 55 db over the band extending from 10.7 to 11.7 kmc. One could construct two of the single-slab isolators (whose performance is shown in Table 1) and place them in tandem to meet this requirement. Space limitations, however, make it desirable to meet these requirements with just one isolator section. This can be done as follows: A second ferrite slab, similar to that previously described, is placed in the waveguide symmetrically with respect to the center line, as shown in Figure 7. The magnetic field applied to this ferrite is opposite in direction but equal in magnitude to that imposed on the first slab. The RF polarizations at both slabs interact equally with the spin precessions in these slabs, because the spin precessions in each slab are opposite in sense. This comes about because of the reversed dc magnetic fields and because the RF magnetic field polarizations on the right and left sides of the guide are opposite in sense. Thus, each slab contributes to and enhances the field displacement effect. If a resistance strip is placed on each ferrite, the reverse loss should increase appreciably. The theoretically expected electric field distributions for this type of configuration are shown in Figure 7. Full height slabs are shown, but in the actual model partial height slabs are used to lower the impedance mismatch into the isolator.

Performance in the 10.7- to 11.7-kmc band and values of operating parameters of a double-slab isolator are shown in Figure 8. As shown, the

THE AUTHORS

S. WEISBAUM received B.S. and M.S. degrees in Physics from New York University in 1947 and 1948 respectively. In 1950, he joined the N.Y.U. faculty as Physics Instructor, and received a Ph.D. degree in Physics from that school in 1953. In the same year, Mr. Weisbaum joined the Laboratories where he initiated exploratory work on ferrite devices in a development group. He worked on the development of a field displacement isolator in 1954 and then became a member of a newly formed group on ferrite devices in the Solid State Device Development Department. Before leaving the Laboratories to form a group doing similar work, Mr. Weisbaum was concerned with isolators for other transmission systems and circulators, and with the resonance behavior of ferrite loaded waveguides.

H. BOYET received the B.S. degree from the College of the City of New York in 1944. After several years of research and development in aerodynamics with the National Advisory Committee for Aeronautics at Langley Field, Virginia, he joined the faculty of New York University, physics department, in 1948. He received the Ph.D. degree in physics from that school in 1953. In the same year, Mr. Boyet joined the Laboratories where, until his recent acceptance of another position, he was engaged in solid state device development in the field of microwave ferrite devices including ferrite scanning antennas, isolators and circulators.

reverse loss is about 70 db over most of the band, while forward loss reaches a maximum of 1.2 db at the high end of the band. In subsequent models, the forward losses have been limited to less than 0.9 db over the entire band.

A direct comparison can be made of the performance of the double-slab field displacement isolator with a double Faraday rotation isolator reported previously. In the 10,700- to 11,700-mc band, the Faraday device gave a maximum forward loss of 1.0 db and a minimum reverse loss of 30 db. In general, the reflections from the field displacement isolator are much less than those from the Faraday type isolator.

The principal reasons for the superiority of the field displacement isolator are as follows: the rectangular to circular waveguide transitions needed in conjunction with the Faraday isolator must be either long tapered devices or relatively narrow band structures for small reflections; the maximum reverse loss in the Faraday device is limited by the ellipticity inherent in the circular waveguide, whereas in the field displacement isolator the reverse loss is limited by the length of the device; to maintain low forward loss and high reverse loss over a broad frequency band in the Faraday device, various methods must be employed, all of which require total lengths that are greater than those obtainable in isolators of the field displacement type.

The field displacement isolator has shown most excellent results to date. Laboratory models have been constructed for microwave relay system tests

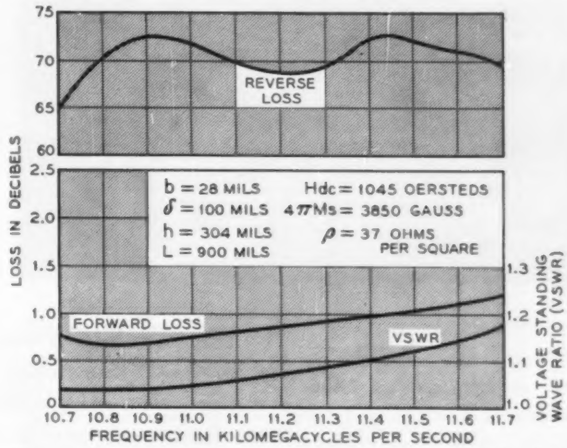


Fig. 8 — Typical performance of double-slab isolator operating in the 10.7- to 11.7- kmc band.

(5,925- to 6,425-mc/sec), system tests and field trials (10,700- to 11,700-mc/sec), and for research work at K-band frequencies (24,000 mc/sec). Exploratory work has also been started on isolators for the 3,700- to 4,200-mc/sec band.

Techniques for Soldering Aluminum

Simple and effective techniques for soldering aluminum and its alloys as well as galvanized metals have been developed by G. M. Bouton and P. R. White, of the Metallurgical Research Department. These techniques employ an inexpensive and stable zinc-base alloy as a preferred solder, and no flux or vigorous abrasion is necessary. Joints in aluminum made by these methods are stronger than commercial aluminum itself.

Because of their simplicity, the techniques are expected to find widespread applications both in industry and in the home workshop. They are most effective for those types of joints where the surfaces are accessible for manipulation with the solder stick, such as butt and "T" joints.

Long-term stability of the soldered joint is assured by the rigid exclusion from the high-purity zinc-base alloy of deleterious elements such as lead, tin, bismuth and cadmium to prevent intergranular corrosion. A fraction of a per cent of magnesium may be added to enhance stability, and up to several per cent of aluminum may be included.

In soldering aluminum it is not necessary to remove rolling mill oils or the surface oxide from the area to be wetted. A single stroke of the solder stick across the heated aluminum surface will cause the solder to penetrate the oxide and wet the aluminum. The normally tenacious oxide film is lifted off much like paint peeling from wet wood. This raised oxide coating may then be wiped aside.

Surfaces thus wet can be joined by bringing them together and adding more solder by drawing the solder stick across the hot metal pieces. Heat may be applied electrically or by means of torches burning common fuels.

This soldering technique is equally effective for joining galvanized surfaces without a flux. Joints produced by this method are strong and stable.

Effective Patents: A Cooperative Effort

R. M. PORTER *Patent Department*

The responsibility of the Laboratories is often described as that of providing increased knowledge and improved techniques in the field of electrical communications. In addition to this fundamental job, however, the Laboratories is also responsible for protecting the results of its work. Only the closest sort of cooperative effort between members of the technical departments and patent attorneys can result in the strong patent position needed to provide this protection. The ferrite isolator described in the preceding article illustrates how effective patents can result from such cooperation.

A strong patent position in a field in which the Laboratories has made important contributions, is usually the result of a number of specific patent applications. Such a group of applications is generally filed over a period of months or even years, and at first glance the individual applications may not seem to be related. Their basic ingredients, however, are the advances in technology that meet the requirements for patentable invention. These advances, together with good workmanship by patent attorneys and the very important element of inventor-attorney cooperation, set the stage for the protection of property through patents as provided by the Constitution.

Such a patent position fulfills two important objectives. First, it provides some assurance that others will not be able to obtain patents on the results of our original work and then prevent us from freely using our own developments. Second, these patent rights provide values that may be exchanged for rights under the patents of others. These two important results contribute substantially to our ability to continue to provide high-grade communication service at reasonable cost.

In the above photograph, inventor E. H. Turner (right) places waveguide containing asymmetrically located ferrite element in transverse magnetic field to demonstrate to Patent Attorney R. M. Porter how a non-reciprocal rotation may be produced for many transmission applications.

An excellent example of both aspects of the growth of a strong patent position is the patent history of the field-displacement isolator. This device, used to suppress the unwanted effects of microwave reflections in radio-relay systems, is the subject of specific patent applications prepared for the inventors S. Weisbaum, H. Boyet and F. J. Sansalone. With these applications on file, a good start is made toward fulfilling the first objective, since others cannot also patent the same device.

Fulfilling the second objective is more complicated and involves the interrelationship of those applications that at first glance may seem to be unrelated. For example, the fundamental concept of "field-displacement" was developed by S. E. Miller of the Holmdel Laboratory. A patent application based on his work disclosed a number of different field displacement devices, and a supplementary application, filed later, included a disclosure of a forerunner of the present isolator. This early device, like the present isolator, included an off-center ferrite element to displace the field, and a resistive vane to provide non-reciprocal attenuation for the displaced field.

The patent application on Miller's basic work in-

cluded broad claims — word definitions that set forth the essence of the invention and establish the bounds of the inventor's contribution. Claims of varying scope were drafted in an effort to stake out, as accurately as can be done by words, the area represented by Miller's inventive contribution. This is also the area from which the patent owner is entitled to exclude others. In the case of Miller's application, this area includes the improved isolator developed by Weisbaum and his associates.

An interesting thing about our patent system is that the claims actually define combinations of structural elements and how they interact without any necessary regard for the ultimate use or function of the combination as a whole. Thus, the patent law provides a way in which a basic structural combination found in an early device can be traced through to a later device although the two may not look alike, function alike, or even be related from a strict engineering point of view. As a result, there are many examples in the patent files of useful and operative devices that are primarily of speculative value since they have no particular technical significance in current developments but become very important from a patent standpoint.

They become important because they may involve structural features that are common to technically important devices that may be developed later. Claims to common features are obtained on the strength of the patent disclosure of a first device. Thus, claims made for the first device also describe broadly or cover the later and possibly more important invention. The field displacement isolator affords an excellent example of this aspect of claim coverage. Its patent history can be traced through applications filed for a number of inventions which include claims that define features of the isolator itself.

One part of this history is represented by the work of W. H. Hewitt of the Whippany Laboratory. Hewitt invented and tested a magnetically variable attenuator that comprised a ferrite vane supported in a waveguide. This attenuator was not an isolator, since its action was completely reciprocal, and it was primarily of speculative value.

As a result of combined technical and patent judgment, however, a patent application was filed for Hewitt in May, 1950. Because of the pioneering nature of Hewitt's work, it was possible to include broad claims in this application to a transversely biased element of ferrite partially filling a rectangular waveguide. Since this is a structural combination found also in the field displacement isolator, when this patent was granted it became one of the first Bell System patents to establish broad claims in the areas which include the isolator.

Patent Attorney I. Kayton obtains detailed information from inventor S. E. Miller to be used in the prosecution of a divisional application on the field displacement isolator. The divisional application is based upon the original and was prepared by Kayton to highlight and specifically claim the isolator using the field-displacement effect.

An example of one early device that looks quite different from the isolator was an invention by E. H. Turner of the Holmdel Laboratory. Turner contributed to the non-reciprocal ferrite art and hence to the isolator by placing a transversely-biased element of ferrite off-center in a round waveguide. He observed a non-reciprocal polarization rotation, similar to the Faraday effect. This non-reciprocity was explained on the basis of circularly polarized magnetic field components at the position of the ferrite. A patent application was filed on the results of Turner's work. Claims have been allowed in this application which cover non-reciprocal devices that comprise a ferrite element located off-center in the cross section of a waveguide at a point of predominant circular polarization. Since this location is responsible for the non-reciprocal action in the isolator as well, the Turner patent will become another contribution to our patent position on the isolator.

Additional examples could be cited to trace the Bell System patent position back to an application, filed in 1943, for A. E. Bowen on a resistive-vane attenuator. The field displacement isolator is therefore a merger of many different and sometimes unrelated structural combinations. It includes a waveguide with a transversely biased vane of fer-

Patent Attorney A. C. Rose compares patent application drawings with original entries in inventor S. E. Miller's notebook. This was the original application, prepared by Rose, to seek protection for the broadest principles involved in the field displacement isolator effect.

rite (as in Hewitt's invention) that is located off-center to produce nonreciprocity (Turner), with a resistive vane (Bowen), and so on back to other waveguide patents. The thread of claims runs through them all.

Drafting claims is not simple; as in other phases of the preparation of a good patent application, it entails the closest cooperation between the inventor and his patent attorney, and in some cases, the associates of both. The inventor is best qualified to evaluate his contribution and its potential applications in terms of the known art. The patent attorney, because of his qualifications and detached viewpoint, can frequently suggest aspects of the invention which may not be immediately apparent to the inventor. Between the inventor and the attorney, however, all aspects of the invention can be considered and the best patent application prepared.

It is evident that much of the basic work leading to and culminating in the field displacement isolator was done at Bell Laboratories. Outside inventors, however, have also made and claimed their contributions. Some of the earliest of these we know about because they are represented by granted patents. As to others, we can only guess, since applications are secret while they are pending in the Patent Office. During the prosecution of our own applications it is possible that we may become involved in a priority contest – an interference proceeding – with one of these outside inventors to determine who first invented some specific stage in the isolator evolution. The outcome of such a contest may depend in large measure upon the records that our inventors have kept, and on how good a patent job has been done.

If important patents relating to some aspect of the new isolator are obtained by others, it is essential that these patents are not infringed by us. Therefore, Laboratories patent attorneys will make a careful search of all non-Bell System patents that might apply before the isolator is put into use in the Bell System. This procedure is aptly termed a "right-to-use" study. It is considerably more than just a search for isolator patents. From one point of view, the isolator is also a resistance vane attenuator and patents on this subject matter must be searched. Similarly, it can be regarded as a waveguide specially loaded by dielectric material. There are patents on this. The composition of the ferrite itself or the composition of the material used in the biasing magnets may be subject to patents held by others. All the patents of interest must be studied individually and thoroughly to insure that we do not infringe the rights of others.

As the result of such a study, we may conclude that, in our opinion, the patent in question or its applicable claims are invalid. One reason for this might be that the Patent Office did not consider certain prior art when the patent in question was granted. In some cases, we may already have permission from the owner of the patent to use its subject matter. This is what lawyers call a "non-exclusive license." In other cases, however, the Bell System may have to seek this permission by the

Patent attorney R. T. Holcomb (right) and W. H. Hewitt, Jr., observing transmission performance of ferrite structure within a waveguide.

purchase of such a license. Where possible, it is usually preferable to obtain the rights needed by trading licenses under Bell System patents – "cross-licensing" is the technical term for this.

The ultimate goal is to maintain the freedom to use the best technical developments known, and thus to give to Bell System customers the best communication service sound business can provide. To this end, our inventors and patent attorneys must cooperate to build a sound patent position. Only in this way can the Bell System be free to use its own inventions and to gain valuable patent rights which may be traded for our right to use patents held by others.

THE AUTHOR

R. M. PORTER, a native of Dallas, Texas, received a B.S. degree in Electrical Engineering from The Rice Institute in 1948 after a wartime interruption as a Naval Aviation Electronics Technician. He immediately joined the Laboratories Patent Staff and commenced the study of law at New York University, receiving an LL.B. degree in 1952. He is presently patent consultant to and attorney responsible for patent work originating in the Radio Research and Solid State Device Development groups. He is a member of Tau Beta Phi, Delta Phi Legal Fraternity, The American Bar Association, and the New York and Patent Office Bars.

Frederick R. Kappel Addresses Telephone Pioneers Assembly

Following the annual banquet of the Telephone Pioneers General Assembly in Philadelphia on September 19, Frederick R. Kappel, President of A.T.&T., told the Assembly that opportunities and the need for pioneering in the telephone industry are greater today than ever before. Speaking before 7,200 members – the largest gathering of telephone people ever assembled – Mr. Kappel called telephone pioneers the "finest group of people in the world – and I mean real people in a real world with all its problems."

"As individuals, we can disagree from time to time," Mr. Kappel said, "we can be critical of specific things, but we are fully together on this: We know the success of the business is vital to each of us, and that this success comes only from each of us doing his or her full part."

One of the important areas stressed by Mr. Kappel was that of earnings. To provide the best possible service at the lowest possible cost was a pioneering pledge a generation ago, and it still holds today, he stated. "In the postwar period as a whole, we have been under very severe regulation. Telephone earnings have been much too low. For many companies, they have improved somewhat in the last few years, but they are still not up to a level which would really assure our ability to provide, over the long pull, the most and best service at the lowest price."

Mr. Kappel told the gathering that, to a considerable extent, the public has come to think that low earnings mean low rates, and good earnings mean high rates. "This is not true and we – everyone of us – have a pioneering job to change the climate of public opinion."

Mr. Kappel also discussed several other areas in which pioneering work must continue. One is that of providing "a business atmosphere in which telephone people can realize all their abilities and also their personal goals." Second, "We can use a lot of pioneering initiative in finding ways to be at home" in the communities we serve, Mr. Kappel said, for "only thus will we understand what communities everywhere expect of us, and only thus will they understand what we are trying to do." Our services are increasingly mechanized, Mr. Kappel pointed out, yet we must be at home in every one of these communities. Third, Mr. Kappel told of the need for constant betterment of existing service and the development of new services. "As we broaden our 'line,'" he said, "each step calls for pioneering judgment all through the organization."

In the manufacture of transistors, diodes and other semiconductor devices, inadequate control of surface technology may lead to serious degradation of initial performance and long-term reliability. Much of this trouble is known to be associated with a thin film of oxide on the semiconductor surface. Though much remains to be learned, recent experiments on the effects of light and of electric field on germanium surfaces have helped to establish the basic physics and chemistry of these effects.

Transistors, Reliability and Surfaces

C. G. B. GARRETT *Physical Research*

When Bell Laboratories announced the transistor back in 1948, engineers held out hopes the latest electronics device would realize a fifty-year-old dream: an amplifier that would consume practically no power, and would last forever. So far, it has never quite managed to fulfill the latter hope. Right from the start Laboratories engineers could see one reason why not: every transistor has a surface. And what went on there was a mystery. Many Laboratories people realized the importance of cracking the problem. In several Laboratories departments, an all-out effort was begun to find out what goes on at a semiconductor surface, and control it. Today, the job is half done. Many technological problems remain. But the surface is no longer quite the enigma it was. Understanding has been set on a solid groundwork of physical and chemical experiment and theory.

Transistors made of germanium or silicon are usually etched. Though quite clean by ordinary standards, an etched surface doesn't consist of just semiconductor and then nothing. There is always a film of oxide between the semiconductor and its surroundings, and the thickness of this oxide is not directly under one's control (one estimate: five atomic layers). Next, the oxide doesn't fit very well on to the semiconductor (Figure 1). An open, porous material, rather like silica gel, the oxide soaks up water and metal ions, and hides them in the gaps and spaces in its structure. And quite tiny changes in the make-up of this oxide layer are important. Quite far into the semiconductor (for example: 10,000 atoms deep), the numbers of holes and electrons respond to small variations in the impurities present in the oxide. Sometimes, the oxide layer likes to give up electrons to the semiconductor, leaving the oxide positively charged. Inside the semiconductor, in a 10,000 atom deep, sub-surface layer, there must then be more electrons and fewer holes than before. Or the oxide may prefer to take up electrons, giving instead a surface region in the semiconductor having fewer electrons and more holes. (See Figure 2.) Imperfectly understood at the present time, the tendency of the oxide to donate or accept electrons is certainly a function of the precise impurities in the oxide, and so, of the surrounding medium. Whatever the exact mechanism, the charge acquired

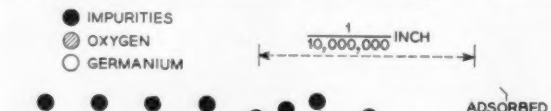


Fig. 1 — Sketch of a germanium surface — an open, porous material.

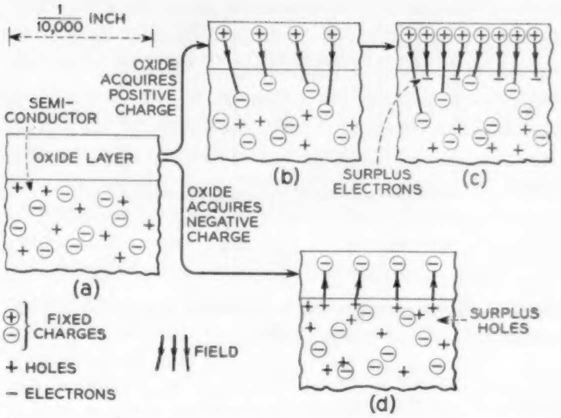


Fig. 2 — Effect of varying the surface charge on carrier concentration near the surface — more electrons and fewer holes, or fewer electrons and more holes.

by the oxide layer is called "ionic charge," and is the most important factor in determining how the surface affects the device properties.

How does all this affect the operation of a transistor? To date, engineers have reported the following items:

The collector characteristic may not saturate properly, i.e., the collector current may be larger than it should be, and increase with collector voltage.

The breakdown voltage of the collector — that voltage at which the collector current suddenly becomes very large — *may be low and variable.*

The current gain (alpha) *may be low.*

There may a direct, ohmic, path between the emitter and collector, giving something like a short circuit.

The emitter efficiency may be low, because of a direct ohmic path between emitter and base.

The noise may be high.

All of the transistor characteristics may change with time, particularly under load and at elevated temperatures. In extreme cases, the whole collector characteristic may "collapse" suddenly, in an irreversible way.

Why are these troubles blamed on the surface? Because they can be changed by changing the etching procedure, and are sensitive to the gas or other environment with which the device is surrounded. Figures 3, 4, and 5 show some of the reasons why.

Figure 3 shows an n^+p junction under reverse bias. ("n^+" means "heavily-doped n-type"; "reverse bias" means that sign of bias which causes the junction current to saturate: in this case, the n^+ side positive and the p side negative.) Shown as a simple diode, this junction could also be the collector of an alloyed npn transistor. The n^+ side, properly a semiconductor, may be thought of as just a well-conducting sink for electrons. On the p side, the lines are drawn to show the flow of minority carriers (electrons) towards the junction, and they represent current flow under the reverse bias. The more lines, the more current. The illustration shows a number of these lines starting on the surface, at "surface traps." A trap is something that tries to maintain holes and electrons at their equilibrium concentrations. If there are too many carriers about, traps will help them to recombine: if there are too few, traps will generate some more. Near a reverse-biased junction, there are always too few, because, as fast as they are generated, they diffuse to the junction and get collected. So, the more traps, the more saturation current. And the number of traps depends on the state of the oxide, so on the surface treatment and environment.

Drawn on a larger scale is Figure 4, which also shows an n^+p junction under reverse bias. In this picture, arrows show lines of force (explanation: lines showing the direction of the electric field at each point; each line begins and ends on an electric charge; the more lines, the greater the field). Assumed negative is the charge in the oxide film, so

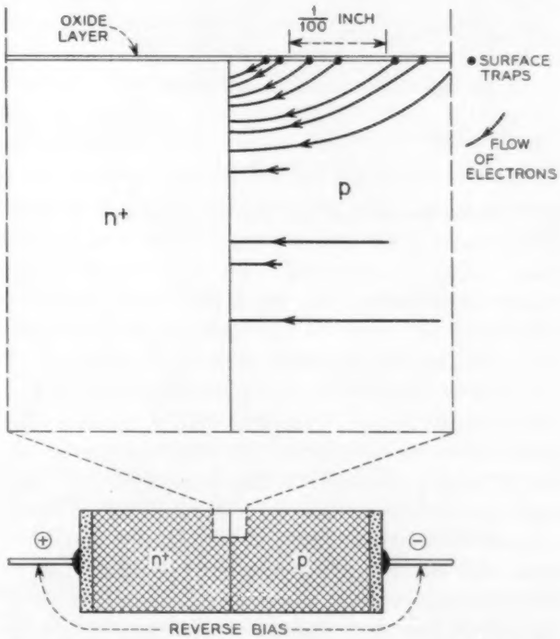


Fig. 3 — Generation from surface traps — the more traps, the more saturation current.

that some of the lines of force can end there instead of in the body. The result is to reduce the width of the junction region near the surface and to pack the lines more closely there. The field being always highest just under the surface, breakdown occurs there first as the bias applied to the junction is increased. Now the breakdown voltage too is controlled by the surface, and so by what is done to it.

Also indicated in Figure 4 is the fringing field outside the semiconductor. This field is quite high (example: 100,000 volts per inch). If now the metal (or other) ions in the oxide are free to move, there arises a leakage current that further deteriorates the saturation of the junction. Worse still are the long-time effects. As the ions change

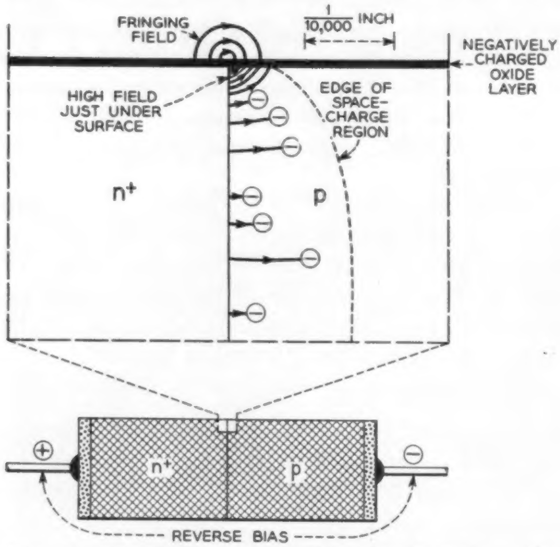


Fig. 4 — Conditions for surface breakdown — the more lines, the greater the field.

their places on the surface, the arrangement of lines of force shown in Figure 4 must alter. The breakdown voltage thus varies with time. Particularly severe are these troubles when there is an appreciable amount of water on the surface (probable reason: because the ions are then more mobile).

Shown in Figure 5 is a more subtle surface effect. This picture shows a transistor with a peculiar ailment: over the base layer, the *minority* carrier of the interior (electrons in the p region) has become the *majority* carrier near the surface. Giving a direct ohmic path between the emitter and collector, this effect arises from a large *positive* charge in the oxide layer over the p-type base region (See (iii) of Figure 2). For an n-type base layer, a large negative charge would be called for. Called an "inversion layer" or "channel," this effect can

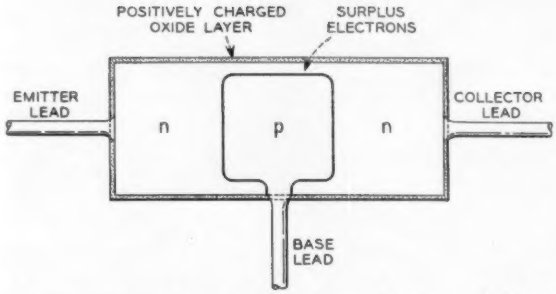


Fig. 5 — Transistor with a channel across the base —this effect can be troublesome.

be troublesome even in diodes. The "channel" effectively extends one region over the surface of the other, giving an increased area for the collection of minority carriers, and thereby increasing the saturation current.

The surface has not yielded its secrets easily. Much careful experimentation has been required to reach the conclusions outlined above. Much of the effort has gone into the problem of elucidating just how the holes and electrons are distributed in the surface region of the semiconductor. Of particular value have been two kinds of experiment: the study of the effects of applying an electric field normal to the surface, and the study of the various effects of illuminating the surface. Carried out with simple, single-conductivity type samples rather than transistors, these investigations have been pushed to the stage at which it is now possible to obtain quantitative information on the distribution of holes and electrons near the surface, and on the properties of the surface traps.

In a typical, straightforward, field-effect experiment, the apparatus might look something like that shown in Figure 6. The scientist applies a high field in a direction normal to the semiconductor surface, looks for a change in the resistance of the slice. Reason for the change in resistance may be seen from Figure 2. The numbers of holes and electrons near the surface respond to anything that sets up a field normal to the surface. In Figure 2 the field is shown arising from charge in the oxide film, but it could also be an applied,

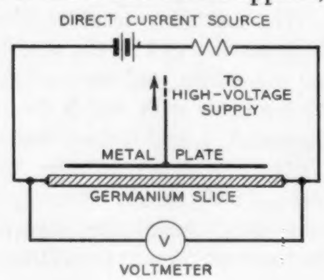


Fig. 6 — The field effect experiment — are these the same traps?

external field. Coaxed into being by the application of a high voltage to the metal plate in Figure 6, the extra surface charge must appear as a change in the numbers of electrons or holes, and so in the resistance of the slice. But now comes the catch: not all the carriers that appear (or disappear) are (or were) free to conduct electricity. Some of them get trapped at the surface. During the last two years, scientists were debating the question: are these the same traps that generate extra current at the surface of a pn junction? Careful measurements of surface generation rates were set beside the results of field-effect experiments. The conclusion: the two sets of traps are the same. Pursuing the field-effect technique to its limit, scientists have been able to use it to determine the actual magnitude of the surface charge in the absence of field, i.e., whereabouts the field-free surface fits into the scheme of Figure 2.

The photo-effect techniques are also valuable. Drawn to show a particularly simple case, Figure 8 indicates the life-history of an extra electron created in p-type material by illumination of the sample, from its birth in the photo-excitation process to its death in recombination at the surface. The surface is drawn to correspond to case (iii) of Figure 2: there is a positive charge in the oxide layer, and a field directed away from the surface. Thus, the potential is higher at the surface than inside, as shown in the top diagram of Figure 8. In the second picture, an extra electron has been created by photo-excitation and starts moving in the direction of the arrow. (*Against* the field, since an electron carries a negative charge.) In the third picture, the electron has moved up to the surface, charging it up negatively and reducing the potential there. In the fourth diagram, the electron has been trapped. The potential at the surface is still low, but the electron is no longer free to take part in conduction. In the last picture, the electron has stayed in the trap long enough for a hole to wander up close to it. The electron and hole annihilate one another, and the surface has returned to its original condition.

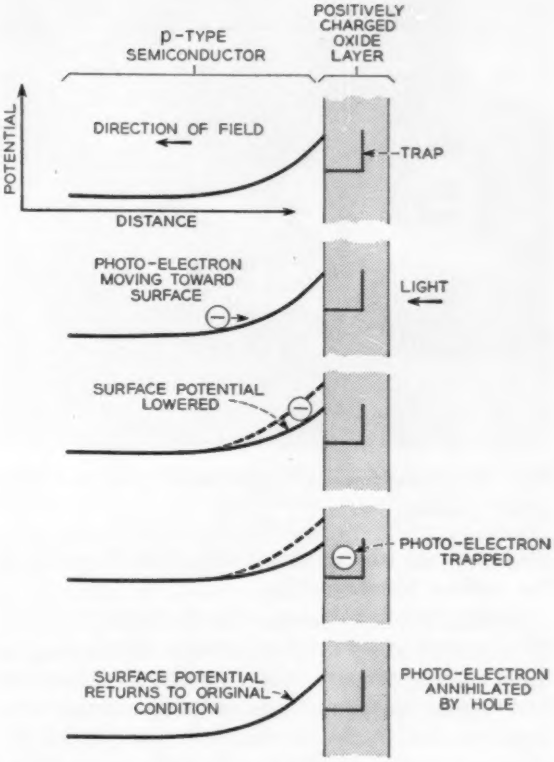


Fig. 8 — The history of a photo-electron — the electron has moved up to the surface.

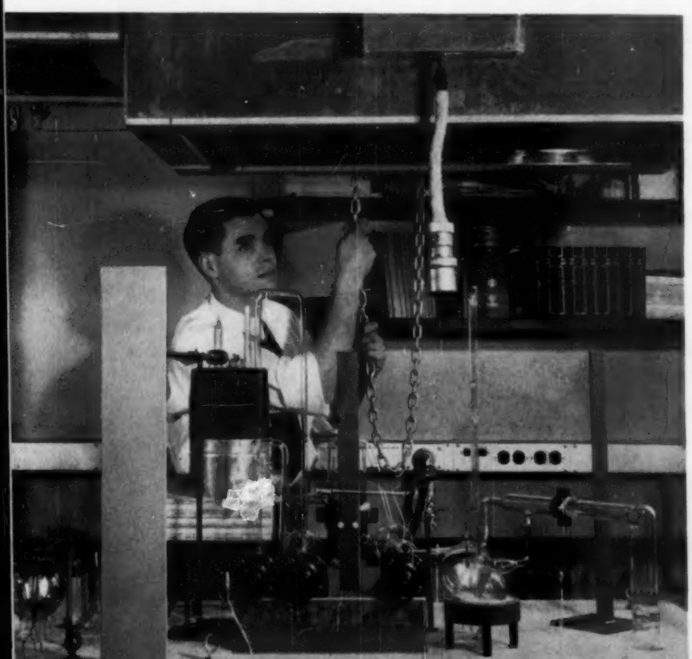
Though this story is greatly simplified, it shows up the following effects of illuminating a sample, all of which are important and may be measured:

Photoconductivity. Extra carriers, created by light, add to the conductance of the sample.

Surface photo-voltage. Illumination of the surface changes, in general, the potential difference between the surface and the interior. This may be seen as a change in work function or contact potential.

Surface recombination. Extra carriers may be annihilated at the surface. This is the reverse of the process shown in Figure 3. Traps that can create carriers can also destroy them. Actually, the magnitude of the photoconductivity and surface

Fig. 7 — P. S. Meigs raising oven from ultra-high vacuum equipment used during investigations of clean surfaces of semiconductors.



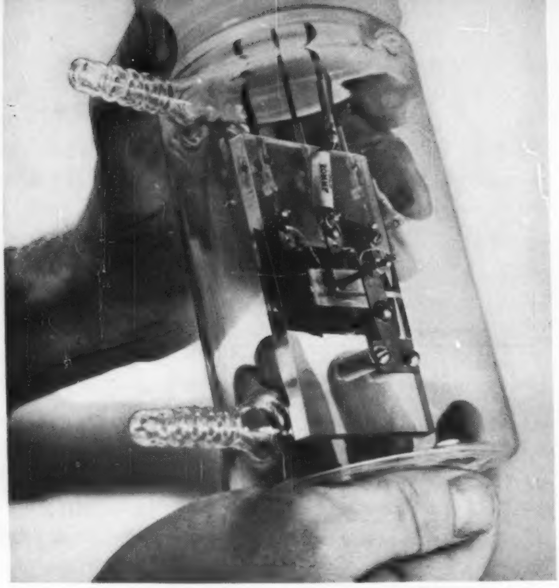


Fig. 9 — Experimental apparatus used in field-effect studies.

photo-voltage in a given steady light depends on the surface recombination.

Making detailed studies of these effects, physicists have arrived at a fairly complete understanding of those surface properties of germanium and silicon that depend on the numbers of holes and electrons. Experimenters make careful measurements on the electrical surface properties of single-conductivity slices of material, and use them to interpret the surface-dependent device characteristics under the same chemical conditions. But this is not the whole story. Chemical control and understanding of the atomic layers outside the semiconductor is also needed. Aiming at the ability to produce a perfectly clean germanium surface, chemists have developed techniques for knocking off the contaminated surface region with accelerated rare-gas ions. The resulting surface has then to be preserved in ultra-high vacuum (example: 1/10,000,000,000,000 atmosphere), to prevent new contaminants sitting down on the surface before one can make measurements on it. Then various contaminants can be introduced in a controlled way. These experiments are costly and difficult. But of one thing Laboratories scientists are confident: the chemical control problems will be mastered just as some of the physical ones have been. And a soundly-based technological control will follow. The whole story is just another example of Laboratories scientists and engineers working together to develop a new science and master a new technology.

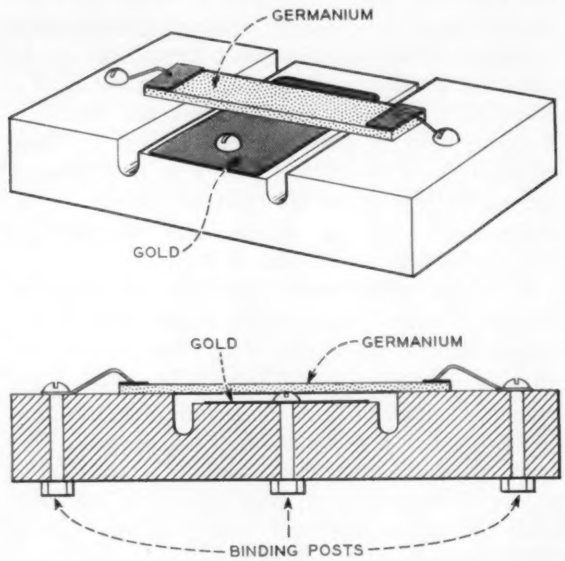


Fig. 10 — Experimental arrangement for field-effect studies.

THE AUTHOR

C. G. B. Garrett, a native of Ashford, Kent, England, received the B.A. degree from Cambridge University (Trinity College), in 1946, and the M.A. and Ph.D. degrees, also from Cambridge, in 1950. He was an instructor in Physics at Harvard University from 1950 until 1952, when he joined Bell Telephone Laboratories. Before coming to the Laboratories, his principal research was in the field of low-temperature physics, with particular reference to paramagnetics. At the Laboratories, he has been engaged in research on semi-conductor surfaces. Mr. Garrett is the author of "Magnetic Cooling" (Harvard University Press, 1954) and of numerous technical papers in British, French, Netherlands and American journals. He was Senior Scholar of Trinity College, Cambridge, in 1945, Twisden Student of Trinity College, 1949, and is a Fellow of the American Physical Society.

Air-Ground Telephone Trial over Detroit and Chicago Areas

A trial of telephone service for airplane passengers began September 15 over the Chicago-Detroit area. Participating in the trial are one government and eleven private planes. While flying in the area, passengers aboard these planes can be connected with almost any telephone in the country.

The experimental service was authorized last April by the Federal Communications Commission for a one-year period. The objective is to determine whether more widespread air-ground public telephone service is practicable and to develop technical knowledge and operating procedures under actual flight conditions. Before the service went into operation, Bell Laboratories personnel conducted tests on the trial system to get further information on radio propagation and other transmission factors in air-ground communication.

Radiotelephone units aboard the planes are connected with the nationwide telephone system via ground radio stations operated by Illinois Bell and Michigan Bell Telephone Companies.

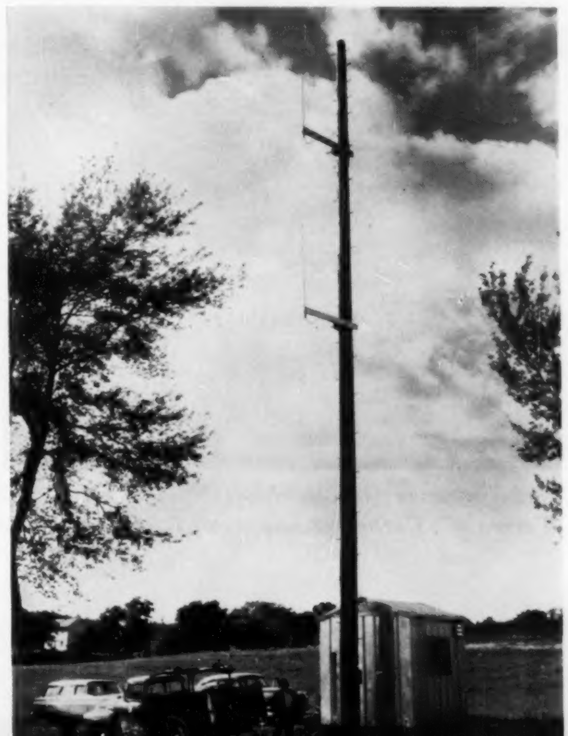
In making an air-ground call, a plane passenger presses a push-to-talk button on his air-borne telephone. This sends a signal to one of the base stations and thence to special "aviation operators" at the company's mobile-service switchboard. Upon reaching the operator, the passenger gives her the number he wishes to call and she makes the connection. Ground-to-air calls may be made by dialing the long-distance number of the telephone company and asking for the aviation operator in Detroit or Chicago. The operator then dials the desired air-borne telephone.

Illinois Bell's radio antenna for this service is on a mast which is already used for radiotelephone service for vehicles, and is located atop the 550-foot Marshall Field Building in Chicago. Michigan Bell's ground station is situated at Dixboro, Michigan, thirty miles west of Detroit.

The telephone companies are temporarily using two radio frequencies in the 450-mc common-carrier band regularly assigned to land mobile-telephone service. Since only one channel will be used for the experiment, only one conversation may take place at one time through each base station. Lightweight radio equipment for use in the airplanes will be made by various electronics manufacturers. Telephone Companies will furnish the ground radio stations, and the air-borne units will be furnished by the users of the service.

Rates during the one-year trial service will range between $1.50 and $5.25 for a three-minute call, depending on the location of the plane and the other party that is calling or being called. For example, a call between an airplane over Milwaukee and a Chicago telephone would cost $1.50 for the first three minutes. These rates are the same as those in effect for coastal harbor service.

Laboratories test installation at Dixboro, Michigan. Commercial trial uses only one antenna. The photograph at the top of the page shows R. V. Crawford, left, and H. J. Bergmann of Bell Laboratories analyzing data on air-ground telephone system.



Three Receive Franklin Institute Medals

One present and two former members of Bell Laboratories have been honored by the Franklin Institute. At the Institute's annual Medal Day ceremonies in Philadelphia on October 16, William G. Pfann of the Metallurgical Research Department received the Francis J. Clamer Medal, and retired Laboratories members John B. Johnson and Warren W. Carpenter were awarded the Edward Longstreth and John Price Wetherill Medals respectively.

The Francis J. Clamer Medal was awarded to Mr. Pfann "in recognition of his discovery and application of zone refining to metals and other crystalline substances." The new technique has tremendously increased the effectiveness of crystallization as a purification method and has led to new uses for the crystallization principle. At the Laboratories and elsewhere, it is widely used in achieving the ultra-pure crystals of germanium and silicon needed for transistors and other semiconductor devices.

A member of the Laboratories since 1936, Mr. Pfann received the bachelor's degree in Chemical Engineering from The Cooper Union in 1940. Besides his work on zone melting, he has been engaged in the development of silicon crystal detectors for use in radar receivers, and in fundamental studies of electrical contact erosion and of dislocations in crystals. He has been an active contributor to the transistor field. The Cooper Union and the American Institute of Mining, Metallurgical and Petroleum Engineers have also cited Mr. Pfann for his work on zone melting, and he has recently completed a book on the subject.

Medal winners (left to right) William G. Pfann, Warren W. Carpenter and John B. Johnson.

Mr. Johnson, who retired from the Laboratories in 1952, received the Edward Longstreth Medal "in consideration of his fundamental investigation leading to the recognition, measurement and understanding of the thermal noise in resistors which forms the basis for the understanding of signal-to-noise ratio in electrical circuits and justly bears the name *Johnson-Noise*."

After receiving the Ph.D. in Physics from Yale University in 1917, Mr. Johnson joined the Western Electric Co. and came with the Laboratories upon its formation in 1925. He has made important contributions in the fields of cathode-ray tubes, thermionic emission in oxide cathodes, and secondary-electron emission from insulators and semiconductors. In establishing the fundamental nature of resistor noise, Mr. Johnson made possible a determination of the lower limit of attainable noise reduction. He is presently head of the Physics Department of the Edison Laboratory, Thomas A. Edison, Inc., in West Orange, N. J.

Mr. Carpenter, who retired in 1951, was awarded the John Price Wetherill Medal "for his important contributions in the field of switching, including the invention of the Automatic Message Accounting System and many related inventions fundamental to the technology of modern telephone switching." AMA is the system used for automatic recording of information required in the handling of long-distance telephone calls.

A member of the Bell System for 38 years, Mr. Carpenter joined the Engineering Department of the Western Electric Co. in 1913 and later transferred to Bell Laboratories. Besides his work with AMA, on which he holds basic patents, he has made significant contributions to many other areas of machine switching systems. Among these are his fundamental work on the decoder for panel equipment, on the "slipped-multiple" principle used in line-finders, and on marker circuits used in modern crossbar systems. For a time after his retirement from Bell Laboratories, Mr. Carpenter served as Research Consultant for the Sandia Corp. and is now part-time consultant at the Hughes Aircraft Corp.

Line-Insulation Testing for Step-by-Step

H. G. SCHAFFER
Switching Systems Development

To insure good service, lines extending from a central office to telephones should be trouble free. Possible sources of trouble in these lines are detected by measuring the electrical resistance of their insulation, particularly in wet weather. Automatic test circuits which do this job in No. 5 crossbar offices have been adapted to test the lines in step-by-step offices in a much shorter time than was previously possible.

Maintaining the insulation resistance of a customer's telephone line is essential to good service. Low values of this resistance may impair the ability of central office equipment to recognize the digits dialed by the customer, or may prevent the equipment from ringing his telephone. It is important, therefore, that customer lines be checked frequently so that insulation troubles may be detected before service failures occur.

Some of the causes of low insulation resistance are cracks in cable sheaths, tree branches touching open wires, damaged drop-wire insulation, and dirty face plates in terminals where drop wires are connected to cable conductors. The nature of these faults is such that they do not appreciably affect insulation resistance during dry weather. During rainy or damp weather, however, moisture, in combination with these faults, materially reduces insulation resistance. At these times, insulation resistance data are very effective in locating faults.

Since wet-weather conditions usually do not persist for long periods, a rapid method must be used for testing insulation resistance so that potential troubles will not impair customer service. In small offices, manual or semi-automatic methods are fast enough to check all lines during these periods, but such methods are inadequate for large offices where automatic test circuits must be employed. Circuits of this type have been developed for No. 1 and No. 5 crossbar offices* and, more recently, for step-by-step offices.

The test equipment units for these systems are similar, in that they all consist of three parts — a test circuit, a control circuit and a trouble recorder. The same test circuit (or insulation-resistance measuring circuit) is used for all three systems. This circuit has been described earlier.† It is a sort of digital ammeter which places a signal on one of four output leads, depending on the value of current flowing through it. These are indicated as the four output signal leads in Figure 1. The test circuit places a signal on lead "OK" if the insulation resistance is greater than the test limit; on lead "H" if the resistance is below this limit but greater than half of it; on lead "M" if the resistance is between one-half and one-quarter of the test limit; and on lead

* RECORD, *October*, 1956, *page* 378.
† RECORD, *October*, 1954, *page* 393.

"L" if the resistance is less than one-quarter of the test limit.

As shown in Figure 1, the current flowing through the measuring circuit is controlled not only by the insulation resistance, but also by variable series and shunt resistances which control the sensitivity of the measuring circuit. These resistors are in the control

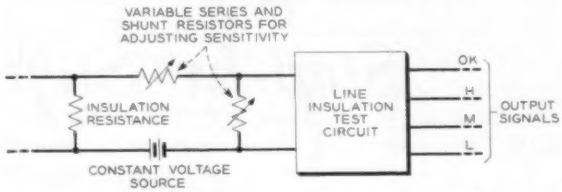


Fig. 1 — Simplified schematic diagram of insulation-resistance measuring circuit.

circuit, which automatically adjusts their values to select one of four possible ranges – designated A, B, C, and D – in which resistance measurements are to be made.

There are three different types of tests made to check for various insulation leaks involving the tip and ring conductors of a line. These tests are: a "short-and-ring-ground" test which checks for low resistance between the tip and ring, or between the ring and ground; a "tip-and-ring-ground" test which checks for low resistance between either conductor and ground, and a "foreign emf" test which checks for leaks between either conductor and the conductors of other lines in the same cable. Each of these tests is so arranged that failure on the initial test may be caused by either or both of two types of insulation fault. To determine which of the two faults actually exists (or whether both are present), a retest under slightly different conditions is made. Three of the four previously mentioned ranges are associated with each of the three types of test. Thus, there are a total of nine combinations of type of test and range, each of which is assigned a number.

To perform the tests, the test set must have access to each line in the central office (or offices) with which it is associated. For economy, this access is provided by the existing test train, made up of one test distributor and 100 test connectors per 10,000 main stations (central office unit).

The test distributor and test connector are 100-point step-by-step switches which operate on a "select-select" basis; that is, they do not hunt but are directed to one out of 100 terminals by dialing two digits. The test connector is so arranged that it may be advanced from one terminal to the next on the same level by transmitting a single dial pulse to it without the necessity of releasing, reseizing and dialing the complete number. This is not true of test distributors in general. A test distributor used for line-insulation testing – located in the same building as the line-insulation test control circuit – is modified so that the control circuit may advance it to an adjacent terminal on the same level without releasing and redialing. This feature is not provided on test distributors which are located in a building distant from that containing the control circuit, because it is not economical to provide the extra leads. For this reason, the speed of testing is higher for lines in the same building than for those in a distant building. The approximate speeds are 6,000 lines per hour for the former and 4,500 for the latter.

Illustrations of a test distributor and test connector are shown in Figures 2 and 4. A line-insulation test control circuit may be associated with more than one test distributor (central office) as indicated in Figure 3. The maximum number of central offices

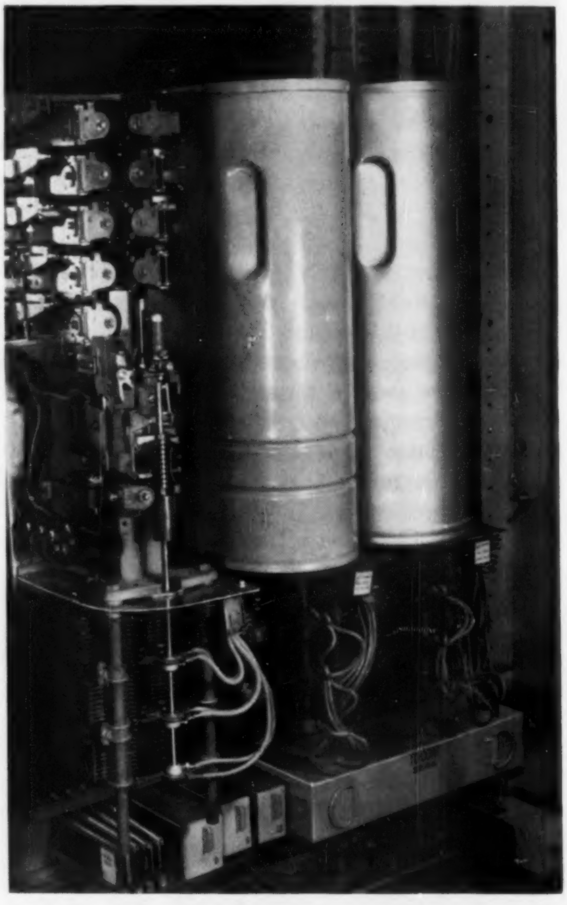


Fig. 2 — Test distributor used for line-insulation test circuit in step-by-step offices.

with which it may be associated is five. This upper limit of five is rather arbitrary and was chosen only because the length of time required to test a larger number of lines would be too great to permit testing all lines during the desired interval – that is, while outside telephone equipment is wet.

Testing is started by selecting any test distributor to which the control circuit has access, and by selecting one of the nine tests. This may be done in several ways: by operating two keys on the circuit-control panel – one to select the test distributor, and the other to select the test; or by making use of the test trunk selector shown in Figure 3 at the test desk, dialing two digits into it, and operating a ringing key. The first digit dialed selects the test distributor in which testing will start; the second selects the type of test and range to be used. The equipment also has an automatic start feature. With a clock, it is possible to start testing at a certain time on any day of the week (for example, at 2 A.M. daily except Saturday and Sunday).

Once started, the control circuit continues in operation until it has tested, one at a time, all the lines to which it has access. It proceeds from one line to the next by stepping a test connector across its terminal bank. Upon reaching the end of each level on a test connector, the control circuit releases and reseizes the connector to step it to the next level. After testing all the lines associated with one test connector, the control circuit advances by stepping the test distributor to its next terminal.

In this manner, the control circuit proceeds through all of the lines in a central office. All busy lines are skipped in the process. Dial PBX lines are also skipped on short-and-ring ground tests because a high-resistance relay winding (connected between the tip and ring on such lines) would appear to be an insulation fault to the test circuit. If a line fails to meet the maximum test condition, the control circuit registers the test results and makes a retest. Should the apparent trouble be due to a receiver off-hook, the control circuit determines this and cancels the record.

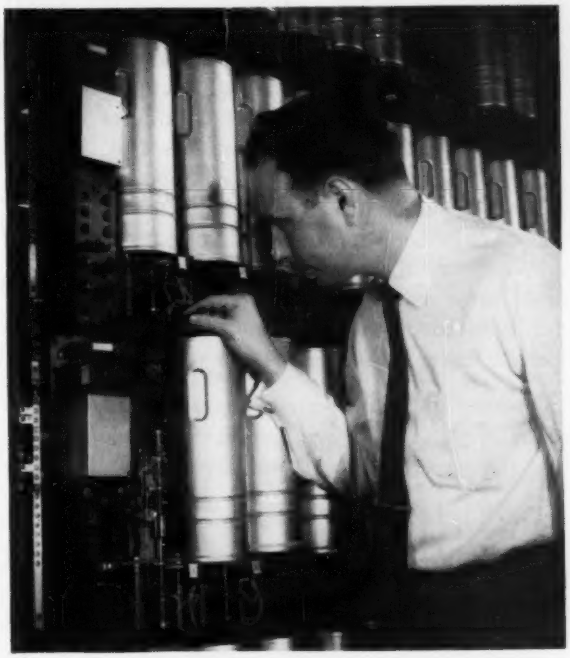


Fig. 4 — I. M. Fine adjusts relay contact spacing in connector for line-insulation test circuit.

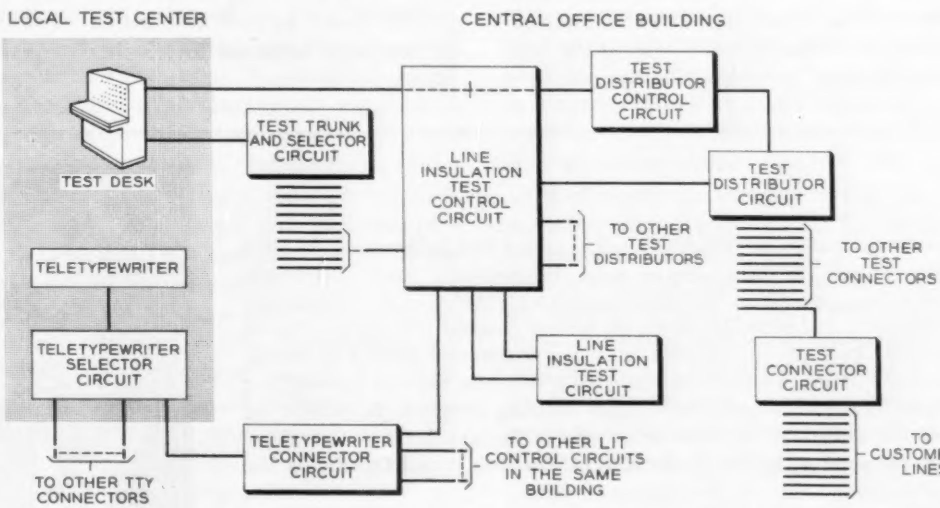


Fig. 3. — Line-insulation test control showing functions of selector and connector circuits.

Having completed testing of one central office unit, the test control circuit advances to another by dropping one test distributor and seizing the next. Regardless of which test distributor it starts with, the control circuit always tests all lines to which it has access unless it is stopped by manual action. It automatically releases itself and all associated circuits at the completion of a test cycle.

Whenever the control circuit encounters a test distributor or test connector that is busy, it waits for it to become idle. Should the busy condition persist for more than about six minutes, however,

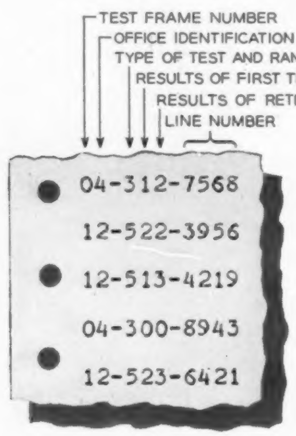


Fig. 5 — Sample teletypewriter record of various line-insulation tests.

the control circuit will light a red lamp on its control panel and sound an audible alarm.

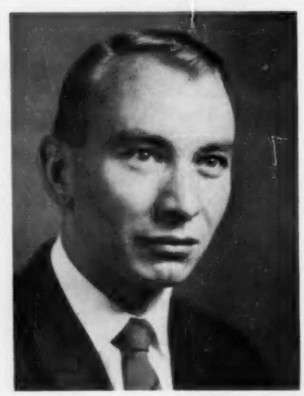
Complete automation of line-insulation testing requires some method of automatically and permanently recording the line number and trouble information for all lines with low insulation resistance. The control circuit registers this information only during the time that it is testing the line. Some external method is needed for providing a permanent record, and this is the function of the teletypewriter indicated in Figure 3.

The control circuit gains access to the teletypewriter through the connector and selector circuits indicated in Figure 3. These circuits permit sharing of the teletypewriter by several control circuits which may be in the same or different buildings. Each time a faulty line is encountered, the control circuit bids for access to a teletypewriter. Having gained access to the teletypewriter, the control circuit transmits the necessary information to it, receives a signal that the information has been recorded, erases the information from its registers, and advances to the next line.

Figure 5 shows a portion of a typical teletypewriter page. The information for one telephone line having low insulation resistance is printed in one line. The significance of each of the characters printed is also indicated. The first record, 04-312-7568, may be used as an example of the meaning of a trouble record. This particular record refers to line number 7568 in the central office corresponding to test distributor number 4 associated with line-insulation test frame number 0. The 312 part of the record is an arbitrary code. In this case, it means that there is a combined leak from the ring to the tip and from the ring to ground of between one-quarter and one-half of the maximum value of the C resistance range. The portion of this leak due to the leak between the ring and tip is between one-half and the maximum value of that range.

This insulation-resistance test circuit is an arrangement for completely automatizing one testing procedure. Although this particular arrangement is new for step-by-step offices, it is only part of a general trend toward automation made necessary by the large increases in telephone customers and telephone services.

THE AUTHOR



H. G. SCHAFFER, a native of Philadelphia, Pa., joined Bell Laboratories in 1951 after receiving a B.S. in E.E. degree from Pennsylvania State University. Except for short assignments in switching apparatus development, transmission systems development, and switching research, he has devoted most of his time to switching systems development. In addition to the design and testing of circuits for telephone dial systems, his work has included a two-year position as switching instructor in the Communications Development Training Program. At present, he is engaged in the design of the transverter circuit for step-by-step centralized automatic message accounting. He is a member of Tau Beta Pi and Eta Kappa Nu.

Laboratories Papers Presented at National Electronics Conference

Significant developments in transistor technology at the Laboratories were covered in papers delivered at the recent National Electronics Conference in Chicago. One of these papers, presented on October 8, described a technique for accurately determining the characteristics of transistors in the grounded-emitter configuration at 30 to 300 mc. The technique has been developed by R. P. Abraham and R. J. Kirkpatrick of the Laboratories. Another paper, presented on October 7 by F. H. Blecher of the Laboratories, discussed practical techniques for designing transistor multiple-loop feedback amplifiers.

Precise measurements of transistor characteristics in the VHF range have been made necessary by the increasing use and potential applications of transistors at frequencies up to 300 mc and even higher. With the technique described by Messrs. Abraham and Kirkpatrick, four measurements and subsequent calculations yield the four complex hybrid parameters, and from these the validity as well as the element values of any equivalent circuit may be determined. The four measurements are h_{11}, the short-circuit input impedance; h_{22}, the open-circuit output admittance; y_{22}, the short-circuit output admittance; and the insertion voltage gain. The calculations needed to transform the measured data to the hybrid parameters are programed on a digital computer.

Measurements are made with the aid of a suitable RF signal source and a Rhode-Schwarz Diagraph, used in conjunction with specially designed coaxial jigs. The Diagraph is an instrument capable of measuring the complex reflection coefficent, or immittance, and the transmission characteristics of the device under test. It contains a chart on which is indicated a vector whose length and angle are proportional to the magnitude and phase angle of the desired complex-wave relationships.

To determine the h_{11} parameter, the input impedance of the transistor with the output terminated in 50 ohms is measured with the Diagraph. The coaxial jig used in this measurement is called the h_{11}-h_{21} jig. Since the h_{11} parameter is defined as the short-circuit input impedance, a small termination error exists and is allowed for.

The h_{22} parameter is measured in much the same manner, except that the chart on the Diagraph is reversed so that admittance can be read directly. An h_{22}-y_{22} jig is used in this measurement. Since the h_{22} parameter is defined as the open-circuit output admittance, the base connection of the jig is ac open-circuited.

The short-circuit output admittance measurement, y_{22} requires an ac short between base and ground, which is provided in the h_{22}-y_{22} jig. Admittance is then measured directly in the same manner as described for h_{22}.

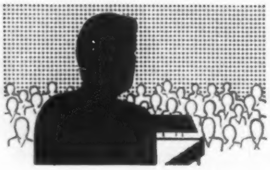
Insertion voltage gain is measured by using the Diagraph and the h_{11}-h_{21} jig. From the voltage gain and the known value of h_{11}, the short-circuit current gain, h_{21}, can be calculated.

Reduction of the measured data to the desired parameters involves calculations which take into consideration three factors: the effects of shunt and series parasitics, imperfect terminations, and the effects of common impedances. The digital computer which makes the computations is programed to take these factors into consideration.

At the Conference, Mr. Blecher described techniques that have been used in the design of a "tandem" feedback amplifier having a gain essentially independent of the transistor characteristics. In addition, the distortion introduced by the output stage is completely eliminated.

Both positive and negative feedback are employed, which enables the designer to achieve transmission characteristics not obtainable with negative feedback alone. Positive feedback is usually avoided in electron-tube amplifiers since it produces an amplifier which is conditionally stable, an undesirable situation where warm-up time is involved. Transistors are particularly suited for the various circuits used in feedback amplifiers since they have essentially no warm-up time.

A criterion of stability has been developed by Mr. Blecher which is useful for calculating the stability margins of multiple-loop feedback amplifiers. This criterion is directly applicable to circuits that employ electron tubes in the common-cathode connection and junction transistors in the common-base connection. It may also be extended to include junction transistors in the common-emitter and common-collector configurations.



Talks by Members of the Laboratories

Following is a list of talks given before professional and educational groups by Laboratories people during September.

132nd National Meeting, American Chemical Society, New York City

Ballman, A. A., see Laudise, R. A.

Brady, G. W., and Sinclair, W. R., *Structure in Ionic Solutions: Lithium Chloride and Potassium Hydroxide.*

Flaschen, S. S., see Luke, C. L.

Frisch, H. L. and Al-Madfai, S., *Surface Tensions of High Polymer Solutions.*

Frisch, H. L., see Mandell, E. R.

Garn, P. D., and Gilroy, H. M., *Determination of Metallic Impurities in Cathode Nickel.* (Presented by H. M. Gilroy)

Gilroy, H. M., see Garn, P. D.

Hassion, F. X., see Thurmond, C. D.

Hawkins, W. L., Lanza, V. L., Loeffler, B. B., and Winslow, F. H., *New Thermal Antioxidants for Polyethylene Containing Carbon Black.*

Hawkins, W. L., and Matreyek, W., *The Effect of Carbon Black on Antioxidants for Polyethylene.*

Hellman, M. Y., see Lundberg, J. L.

Kowalchik, M., see Thurmond, C. D.

Lanza, V. L., see Hawkins, W. L.

Laudise, R. A., and Ballman, A. A., *The Hydrothermal Synthesis of Sapphire.*

Loeffler, B. B., see Hawkins, W. L.

Luke, C. L., and Flaschen, S. S., *Determination of Boron in High Purity Silicon using the Principle of Hydrothermal Refining.*

Lundberg, J. L., Nelson, L. S., and Hellman, M. Y., *Thermal Effects in the High-Intensity Flash Illumination of Polymers.*

Lundberg, J. L., *Predicted Molecular Sizes and Distributions of Equilibrium Polyethylenes.*

Mandell, E. R., Frisch, H. L., McCall, D. W., and Slichter, W. P., *Concentration-Dependent Diffusion in Polyethylene.*

Mandell, E. R., see Slichter, W. P.

Matreyek, W., see Hawkins, W. L.

McCall, D. W., and Slichter, W. P., *Diffusion in Polyethylene: Energies and Volumes of Activation.*

McCall, D. W., see Mandell, E. R.

Nelson, L. S., see Lundberg, J. L.

Sinclair, W. R., see Brady, G. W.

Slichter, W. P., and Mandell, E. R., *Molecular Structure and Motion in Polyethylene.*

Slichter, W. P., see Mandell, E. R.

Slichter, W. P., see McCall, D. W.

Thurmond, C. D., Hassion, F. X., and Kowalchik, M., *Germanium and Silicon Liquidus Curves.*

Wadlow, H. V., *Micromanipulation in Industrial Research.*

Winslow, F. H., see Hawkins, W. L.

12th General Assembly, U.R.S.I., Boulder, Colorado

Danielson, W. E., *Emergence of the Traveling-Wave Tube as a Practical Low-Noise Device.*

Pierce, J. R., *The Source and Nature of Noise in Electron Beams.*

Rigrod, W. W., *Noise Growth in Drifting Electron Streams.*

Scovil, H. E. D., *The Solid State Maser.*

Suhl, H., *Microwave Amplification Using Ferromagnetic Materials.*

American Physical Society, Boulder, Colorado

Lax, M., and Phillips, J. C., *One-Dimensional Impurity Bands* (Presented by Phillips, J. C.).

Meitzler, A. H., and Stadler, H. L., *Piezolectric and Dielectric Characteristics of $BaTiO_3$ Crystals.*

Phillips, J. C., see Lax, M.

Stadler, H. L., see Meitzler, A. H.

Wertheim, G. K., *Temperature Dependence of Capture Cross Sections of Indium in Silicon.*

Annual Meeting of the Institute of Mathematical Statistics, Atlantic City, N. J.

Lloyd, S. P., *Quantization for Least Mean Squares Error.*

Sobel, M., *A Parametric Approach to the Problem of Selecting a Subset Containing the Best Population.*

Terry, M. E., *Applications of Computers to Statistical Problems.*

Wilk, M. B., *Reduced Regression Models.*

Other Talks

Abert, C., *Decision-Making Machines in the Bell Systems,* Rotary Club, Pittsfield, Mass.

Baldwin, G. L., and Booth, D. P., *A Double Precision Interpretive System,* IBM 650 Seminar, Endicott, N. Y. (Presented by D. P. Booth).

Berkery, E. A., *High Stability Power Supplies for Klystrons and Traveling Wave Tubes,* A.I.E.E.-I.R.E. Special Technical Conference on Magnetic Amplifiers, Pittsburgh, Pa.

Booth, D. P., see Baldwin, G. L.

Boyet, H., *Some Recent Work in the Field of Microwave Ferrite Devices,* Weizmann Institute of Science, Rehovoth, Israel.

Calbick, C. J., *Scattering by Residual Gases During Evaporation of Carbon,* Meeting of Electron Microscope Society of America, Massachusetts Institute of Technology, Cambridge, Mass.

Dodge, H. F., *Sampling Inspection*, Fourth Annual Western Regional Quality Control Conference of the A.S.Q.C., San Francisco, Calif.

Dodge, H. F., *Experiences in Sampling*, Phoenix Section of A.S.Q.C., Phoenix, Ariz.

Emling, J. W., *Planning and Programing in Bell Telephone Laboratories*, Class in Advanced Logistics, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio.

Geballe, T. H., see Kunzler, J. E.

Goss, F. A., Jr., and Mallory, H. D., *A New Method for the Measurement of Initiation Times in Hot Wire Ignitions*, Naval Ordnance Laboratory Explosive Sensitivity Conference, Silver Spring, Maryland.

Hull, G. W., see Kunzler, J. E.

Jeffries, C. K., *Starting Torque of Syncro Gear Train at High and Low Temperatures*, Aircraft Gearing Committee, American Gear Manufacturers Association, Denver, Colo.

Karlin, J. E., *Where Will Human Engineering be Ten Years from Now?* Conf. of Human Engineers, sponsored by the Office of Naval Research, Tulsa, Okla.

Kunzler, J. E., Geballe, T. H., and Hull, G. W., *Further Studies on Encapsulated Germanium Resistance Thermometers*, 12th Calorimetry Conference, Portsmouth, N. H.

Legg, V. E., *Survey of Square Loop Magnetic Materials*, A.I.E.E.-I.R.E. Special Technical Conference, Magnetic Amplifiers, Pittsburgh, Pa.

Levenbach, G. J., *Qualification and Life Testing of Electronic Components*, Rutgers Conference on Quality Control, New Brunswick, N. J.

Lewis, W. D., *Individual Creativeness in Group Research*, 11th National Conference on Administration on Research, Washington, D. C.

Matreyek, W., see Winslow, F. H.

Myers, W. E., *The Gyroscope – Basic Principles and Application to Inertial Systems*, Meeting of the I.R.E. Sub-Section, Winston-Salem, N. C.

Pearson, G. L., *Photoprocesses in Elemental Semiconductors*, Symposium on Photochemical Storage of Energy in Liquid and Solid Systems in Vitro, Dedham, Mass.

Sproul, P. T., *6000 Megacycles – The New Highway to Communication*, Lehigh Valley Sub-Section of I.R.E., Bethlehem, Pa.

Storks, K. H., *X-Ray Fluorescent Spectroscopy in Micro and Semi-micro Analysis*, X-Ray School, General Electric Company, Milwaukee, Wisc.

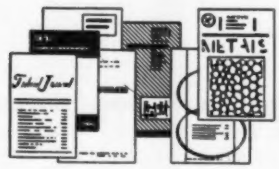
Thomas, D. E., *Design of RF Transistor Amplifiers*, Northern N. J. Section of I.R.E., Montclair, N. J.

Turner, E. H., *A Ferrite Duplexer for the 70-Kmc Region*, Tri-Service Millimeter Wave Symposium, U. S. A. Signal Corps. Engineering Laboratories, Ft. Monmouth, N. J.

Wilder, G. R., *Introduction to Digital Computers*, Mid-State Sub-Section of the A.I.E.E., Winston-Salem, N. C.

Winslow, F. H., Matreyek, W., and Yager, W. A., *Carbonization of Vinyl Polymers*, Conference on Industrial Carbon and Graphite, Society of Chemical Industry, London, England.

Yager, W. A., see Winslow, F. H.



Papers by Members of the Laboratories

Following is a list of the authors, titles and places of publication of recent papers published by members of the Laboratories:

Anderson, P. W., see Shulman, R. G.

Anderson, P. W., *The Reaction Field and Its Use in Some Solid State Amplifiers*, J. Appl. Phys., **28**, pp. 1049-1053, Sept., 1957.

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Frisch, H. L., and Lebowitz, J. L., *Model of a Nonequilibrium Ensemble: Knudsen Gas*, Phys. Rev., **107**, pp. 917-923, Aug. 15, 1957.

Frisch, H. L., and Simha, R., *Statistical Mechanics of Flexible High Polymers at Surfaces*, J. Chem. Phys., **27**, pp. 702-706, Sept., 1957.

Garrett, C. G. B., *High-Frequency Relaxation Processes in the Field-Effect Experiment*, Phys. Rev., **107**, pp. 478-487, July 15, 1957.

Gilbert, E. N., *Knots and Classes of Menage Permutations*, Scripta Mathematica, **22**, pp. 228-233, Sept.-Dec., 1956.

Gyorgy, E. M., *Rotational Model of Flux Reversal in Square Loop Ferrites*, J. Appl. Phys., **28**, pp. 1011-1015, Sept., 1957.

Hittinger, W. C., see McGlasson, J.

Hrostowski, H. J., and Kaiser, R. H., *Infrared Absorption of Oxygen in Silicon*, Phys. Rev., **107**, pp. 966-972, Aug. 15, 1957.

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Liehr, A. D., *On the Use of the Born-Oppenheimer Approximation in Molecular Problems*, Annals of Physics, **1**, pp. 221-232, June, 1957.

Liehr, A. D., *Critical Study of Vibronic Interaction Calculations*, Canadian J. Phys., **35**, pp. 1123-1132, Sept., 1957.

Lowry, W. K., *Trends in U. S. Documentation Research*, Special Libraries, **48**, pp. 364-366, Oct., 1957.

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Mertz, P., *Information Theory Impact on Modern Communications,* Elec. Engrg., **76**, pp. 773-776, Sept., 1957.

McGlasson, J., Peterson, J. W., and Hittinger, W. C., *Some Aspects of Alloying onto Germanium Surfaces,* J. Metals, Trans. A.I.M.E., **209**, pp. 823-827, July, 1957.

McMillan, B., and Riordan, J., *A Moving Single Server Problem,* Annals of Mathematical Statistics, **28**, pp. 471-478, June, 1957.

Pearson, G. L., see Wertheim, G. K.

Peters, H., *Hard Rubber Review – 1955-1956,* Industrial and Engineering Chemistry Materials of Construction, **49**, pp. 1604-1606, Sept., 1957.

Peterson, J. W., see McGlasson, J.

Pfann, W. G., and Dorsi, D., *Magnetic Stirring Technique,* Rev. Scientific Instruments, **28**, p. 720, Sept., 1957.

Pierce, J. R., *What Good Is Information Theory to Engineers,* 1957 I.R.E. National Convention Record, **2**, pp. 51-55.

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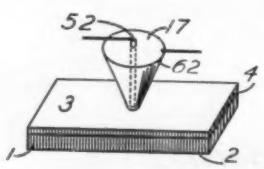

Patents Issued to Members of Bell Telephone Laboratories During August

Badders, W. C. – *Electrical Socket Connector for Printed Circuit Boards* – 2,802,188.

Berger, U. S., and Laidig, J. F. – *Radiant Energy Signaling System* – 2,803,744.

Biskeborn, M. C. – *Methods of and Apparatus for Measuring the Capacitance of an Insulated Wire* – 2,804,592.

Boothby, O. L., and Wenny D. H., Jr. – *Preparation of MnBi Bodies* – 2,804,415.

Boyle, W. S. – *Electrostatic Relay* – 2,802,918.

Burton, E. T. – *Multivabrator Circuit* – 2,802,940.

Dalton, J. F. – *Telephone Handset Shoulder Support* – 2,802,062.

Davey, J. R., and Wilson, A. – *Teletypewriter Station Network Including Mobile Station* – 2,802,937.

Derick, L., and Frosch, C. J. – *Oxidation of Semiconductive Surfaces for Controlled Diffusion* – 2,802,760.

Derick, L., and Frosch, C. J. – *Manufacture of Silicon Devices* – 2,804,405.

Fox, A. G. – *Non-Reciprocal Wave Transmission* – 2,802,184.

Frosch, C. J., see Derick.

Germer, L. H., and Smith, J. L. – *Contact Protection Circuits* – 2,802,149.

Graham, R. E., and Kretzmer, E. R. – *AC Coupled Gate Circuits* – 2,802,954.

Hawks, V. J. – *Balanced Amulitude Modulation with Reinserted Carrier* – 2,804,596.

Kingsbury, E. F. – *Electro-optical System* – 2,804,574.

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Kretzmer, E. R., see Graham, R. E.

Laidig, J. F., see Berger, U. S.

Luckner, L. B., and Reed, E. D. – *Electron Discharge Device of the Cavity Resonator Type* – 2,802,137.

Mahoney, J. A. – *Telegraph Transmission System* – 2,802,050.

McConnell, J. H. – *Multivibrator Circuit* – 2,802,941.

Pfeiffer, S. B. – *Reflected Binary Digital-to-Alanog Converter for Synchro Devices* – 2,803,003.

Reed, E. D. see Luckner, L. B.

Scheideler, C. E. – *Antennas Employing Laminated Conductors* – 2,802,209.

Simkins, Q. W. – *Transistor Amplifier Circuits* – 2,802,118.

Smith, J. L., see Germer, L. H.

Soffel, R. O. – *Pulse Modulation Circuit* – 2,804,595.

Spack, E. G. – *Telephone Ring-Up Circuit* – 2,802,059.

Taris, C. M. – *Electromagnetic Transducer Mounting* – 2,802,905.

Townsend, M. A. – *Gaseous Discharge Devices* – 2,804,565.

Weber, E. H., Jr. – *Amplifier with High Frequency Compensation* – 2,802,069.

Wenny, D. H., Jr., see Boothby, O. L.

Wilson, A., see Davey, J. R.

Zupa, F. A. – *Screw Mounting Having Insulating and Locking Properties* – 2,802,503.

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